PLUME CHEMISTRY STUDIES DURING 1980 IN THE ATHABASCA TAR SANDS REGION

by

J.W. BOTTENHEIM

Atmospheric Dispersion Division
Atmospheric Environment Service
4905 Dufferin Street
Downsview, Ontario
M3H 5T4

for

RESEARCH MANAGEMENT DIVISION

Alberta Environment

Project AS 3.5.6

1984

RESEARCH MANAGEMENT DIVISION
UNEDITED
MATERIAL
O.F. 80

PLUME CHEMISTRY STUDIES DURING 1980 IN THE ATHABASCA TAR SANDS REGION

by

J.W. BOTTENHEIM

Atmospheric Dispersion Division
Atmospheric Environment Service
4905 Dufferin Street
Downsview, Ontario
M3H 5T4

for

RESEARCH MANAGEMENT DIVISION

Alberta Environment

Project AS 3 5.6

1984

This report is made available as a public service. The Department of Environment neither approves nor disagrees with the conclusions expressed herein, which are the responsibility of the author.

TABLE OF CONTENTS

		Page
LIST OF TABLES		v
LIST OF FIGURES		x
ABSTRACT		xv
ACKNOWLEDGEMENTS		xvi
1.	INTRODUCTION	1
2.	OUTLINE OF THE 1980 FIELD STUDIES	3
2.1	Meteorological Conditions	3
2.2	In Situ Monitoring	4
2.3	Filter Pack Collections	7
2.4	Grab Sampling for Hydrocarbon Analysis	7
3.	RESULTS AND DISCUSSION	9
3.1	SO_x Data	9
3.1.1	Percent Sulphur as Sulphate	16
3.1.2	Transformation of SO_2 to Sulphate during the Winter	18
3.1.3	Transformation of SO_2 to Sulphate during the Summer	18
3.2	NO_x and O_3 Data	21
3.3	Hydrocarbons	31
3.4	Dispersion	38
4.	SUMMARY AND RECOMMENDATIONS	45
5.	LITERATURE CITED	48
6.	APPENDICES	50
6.1	Airborne Platform Description and Flight Procedures (INTERA)	50
6.1.1	Aircraft Operations	50
6.1.2	Flight Profiles	57
6.1.3	Meteorological Data	57
6.1.4	System Calibration Data	58
6.2	Descriptive Summary of Case Studies (INTERA)	62
6.2.1	1980 January 09	71
6.2.2	1980 January 10	78
6.2.3	1980 January 11	85
6.2.4	1980 January 13	90
6.2.5	1980 March 18	98
6.2.6	1980 March 19	98
6.2.7	1980 March 20	107
6.2.8	1980 March 21	107

continued ...

TABLE OF CONTENTS (CONCLUDED)

		Page
6.2.9	1980 March 24	119
6.2.10	1980 March 25	119
6.2.11	1980 June 25, 2035-2305	131
6.2.12	1980 June 28, 1230-1540	131
6.2.13	1980 July 94, 1000-1350	131
6.2.14	1980 July 05, 0505-0845, 0920-0950	140
6.2.15	1980 July 07, 0510-0730, 1030-1205, 1340-1605, 1805-1930	140
6.3	Filter Pack Sampling	168
6.3.1	Analytical Methods (M. Gray)	168
6.3.1.1	Filter Pack Design	168
6.3.1.1.1	Low Volume Filter Pack	168
6.3.1.1.2	High Volume Filter Pack	168
6.3.1.2	Preparation of Filters	170
6.3.1.3	Extraction of Filters	170
6.3.1.3.1	Low Volume Filter Pack	170
6.3.1.3.2	High Volume Filter Pack	172
6.3.1.4	Analysis of Filters	172
6.3.1.5	References	173
6.3.2	Filter Pack Data	173
6.4	Hydrocarbon Sampling	173
6.4.1	Analytical Method	173
6.4.1.1	Aircraft Sampling System	173
6.4.1.2	Analysis Procedure	181
6.4.1.3	Calibration	184
6.4.1.4	Discussion of Soecial Problems	189
6.4.2	Hydrocarbon Data	190
6.5	In Situ Monitoring Data	207
6.6	Auxilliary Data	210
6.6.1	Stack Monitoring Data from Syncrude Ltd.	210
6.6.2	Emission Data from Power House Stack of Suncor Ltd.	237
6.6.3	Radiation Data	239
6.6.4	Observations at Lower Syncrude Camp Meteorological Tower	250
6.6.5	Syncrude Acoustic Sounder Data	256
6.6.6	Minisonde Data	258

LIST OF TABLES

		Page
1.	In situ Monitoring Equipment	5
2.	$SO_4^=$/Total-S Ratio as Determined by Filter Pack Sampling during 1980 Plume Chemistry Field Studies	10
3.	Comparison of Apparent Hivol versus Filter Pack Collection Efficiencies	12
4.	C_2H_2 Levels during July, 1980	20
5.	NO_x/SO_x Data during 1980 Plume Chemistry Field Studies .	22
6.	Hydrocarbon Mixing Ratios in Plume Air Sample Collected on 10-1-80, 3 Miles from Syncrude Stack under Ice Fog Conditions	33
7.	Estimated OH Radical Concentrations by Using Hydrocarbon Data	37
8.	Plume Dispersion Calculation Data	39
9.	Dispersion Factors α' and β	43
10.	Aircraft Equipment during January and March 1980	51
11.	Aircraft Equipment during June/July 1980	54
12.	Instrument Calibration Schedule, Winter Studies	59
13.	DAS Channel Allocation	63
14.	Summary of Flight Operations, January/March 1980	69
15.	Summary of Flight Operations, June/July 1980	70
16.	Summary of Measurements, 1980 January 09	74
17.	Fort McMurray Surface Weather Observations, 1980 January 09	75
18.	Summary of Measurements, 1980 January 09	80
19.	Fort McMurray Surface Weather Observations, 1980 January 10	82
20.	Summary of Measurements, 1980 January 10	83

continued ...

LIST OF TABLES (CONTINUED)

		Page
21.	Fort McMurray Surface Weather Observations, 1980 January 11	87
22.	Summary of Measurements, 1980 January 11	88
23.	Fort McMurray Surface Weather Observations, 1980 January 13	94
24.	Summary of Measurements, 1980 January 13	96
25.	Summary of Measurements, 1980 January 13	100
26.	Summary of Measurements, 1980 March 18	102
27.	Fort McMurray Surface Weather Observations, 1980 March 18	104
28.	Summary of Measurements, 1980 March 19	106
29.	Fort McMurray Surface Weather Observations, 1980 March 19	109
30.	Summary of Measurements, 1980 March 20	111
31.	Fort McMurray Surface Weather Observations, 1980 March 20	113
32.	Summary of Measurements, 1980 March 21	116
33.	Fort McMurray Surface Weather Observations, 1980 March 21	117
34.	Summary of Measurements, 1980 March 21	120
35.	Summary of Measurements, 1980 March 24	123
36.	Fort McMurray Surface Weather Observations, 1980 March 24	124
37.	Summary of Measurements, 1980 March 25	126
38.	Fort McMurray Surface Weather Observations, 1980 March 25	129
39.	Summary of Measurements, 1980 March 25	134
40.	1980 June 25 Flight Summary 177-80-3	135

continued ...

LIST OF TABLES (CONTINUED)

		Page
41.	1980 June 25 Flight Summary 180-80-2	137
42.	Fort McMurray Surface Weather Observation, 1980 July 04 ...	138
43.	1980 July 04 Flight Summary 186-80-1	141
44.	Fort McMurray Surface Weather Observation, 1980 July 05 ...	144
45.	1980 July 05 Flight Summary 187-80-1	147
46.	Fort McMurray Surface Weather Observation, 1980 July 07 ...	148
47.	1980 July 07 Flight Summary 189-80-1, 189-80-2, 189-80-4, and 189-80-6	151
48.	Fort McMurray Surface Weather Observation, 1980 July 08 ...	162
49.	1980 July 08 Flight Summary 190-80-1	166
50.	Results of Filter Pack Sampling	174
51.	Retention Time of Hydrocarbons on Durapak (n-octane/ porasil-C) Column	185
52.	Hydrocarbon Data of Samples Collected on 1980 January 09 ..	191
53.	Hydrocarbon Data of Samples Collected on January 10	192
54.	Hydrocarbon Data of Samples Collected on 1980 January 11 ..	193
55.	Hydrocarbon Data of Samples Collected on 1980 January 13 ..	194
56.	Hydrocarbon Data of Samples Collected on 1980 March 18	195
57.	Hydrocarbon Data of Samples Collected on 1980 March 19	196
58.	Hydrocarbon Data of Samples Collected on 1980 March 20	197
59.	Hydrocarbon Data of Samples Collected on 1980 March 21	198
60.	Hydrocarbon Data of Samples Collected on 1980 March 24	199
61.	Hydrocarbon Data of Samples Collected on 1980 March 25	200
62.	Hydrocarbon Data of Samples Collected on 1980 May 11	201

continued ...

LIST OF TABLES (CONTINUED)

		Page
63.	Hydrocarbon Data of Samples Collected on 1980 June 28	202
64.	Hydrocarbon Data of Samples Collected on 1980 July 04	203
65.	Hydrocarbon Data of Samples Collected on 1980 July 05	204
66.	Hydrocarbon Data of Samples Collected on 1980 July 07	205
67.	Hydrocarbon Data of Samples Collected on 1980 July 08	206
68.	Data Tape	208
69.	Report for the 24 h ending 0700, 1980 January 09; o.s.h. clock averages	211
70.	Report for the 24 h ending 0700, 1980 January 13; o.s.h. clock averages	213
71.	Report for the 24 h ending 0700, 1980 January 14; o.s.h. clock averages	215
72.	Report for the 24 h ending 0700, 1980 March 19; o.s.h. clock averages	217
73.	Report for the 24 h ending 0700, 1980 March 20; o.s.h. clock averages	218
74.	Report for the 24 h ending 0700, 1980 March 21; o.s.h. clock averages	219
75.	Report for the 24 h ending 0700, 1980 March 22; o.s.h. clock averages	221
76.	Report fot the 24 h ending 0700, 1980 March 25; o.s.h. clock averages	223
77.	Report for the 24 h ending 0700, 1980 March 26; o.s.h. clock averages	224
78.	Report for the 24 h ending 0700, 1980 June 28; o.s.h. clock averages	225
79.	Report for the 24 h ending 0700, 1980 June 29; o.s.h. clock averages	227
80.	Report for the 24 h ending 0700, 1980 July 05; o.s.h. clock averages	229

continued ...

LIST OF TABLES (CONCLUDED)

		Page
81.	Report for the 24 h ending 0700, 1980 July 06; o.s.h. clock averages	231
82.	Report for the 24 h ending 0700, 1980 July 08; o.s.h. clock averages	233
83.	Report for the 24 h ending 0700, 1980 July 09; o.s.h. clock averages	235
84.	Estimated Daily Emission of SO_2 from the Powerhouse Stack of Suncor Ltd.	238
85.	Lower Syncrude Tower Data, January 1980	251
86.	Lower Syncrude Tower Data, March 1980	253
87.	Lower Syncrude Tower Data, June/July 1980	254
88.	Syncrude Doppler Acoustic Sounder Data during June/July 1980	257
89.	Minisonde Data, July 1980	259

LIST OF FIGURES

		Page
1.	Chart Recorder Traces of Gas Monitors During Sampling of Suncor Plume	6
2.	Comparison of Integrated SO_2 Data from Filterpack and Flame Photometric Sampling (Meloy-285)	14
3.	Comparison of Integrated SO_2 Data from Filterpack and Flame Photometric Sampling (Meloy-285)	15
4.	Ratio $SO_4^=$/Total-S as Function of Plume Travel Time, Determined from Filterpack Data	17
5.	Cross Wind Plume Profile, 1.5 Miles from Syncrude Stack. 1980 July 07, 13:45 MDT	28
6.	Cross Wind Plume Profile, 12 Miles from Syncrude Stack. 1980 July 07, 14:10 MDT	29
7.	Cross Wind Plume Profile, 20 Miles from Syncrude Stack. 1980 July 07, 14:20 MDT	30
8.	Hydrocarbon Content of the Syncrude Plume as Function of Plume Travel Time	35
9.	Comparison of Unormalized Plume Transect Data for SO_2 with True Gaussian Profiles for Arbitrarily Chosen Transects of Successive Plume Samplings on 13-1-80	40
10.	Comparison of Normalized Plume Transect Data for SO_2 with True Gaussian Profiles for Arbitrarily Chosen Transects of Successive Plume Samplings on 25-3-80	41
11.	Cessna 411 Showing Location of Sampling Probes	53
12.	Sensor Units and Data Acquisition System	55
13.	Inside Schematic of INTERA's Cessna 411 Configured for AOSERP Plume Chemistry Study	56
14.	Calibration Curve for Meloy 285	60
15.	Calibration Curve for Meloy 285	61
16.	Calibration Curve for INTERA's Sensors	64

continued ...

LIST OF FIGURES (CONTINUED)

		Page
17.	Calibration Curve for INTERA's Sensors	65
18.	Calibration Curve for INTERA's Sensors	66
19.	Calibration Curve for INTERA's Sensors	67
20.	Calibration Curve for INTERA's Sensors	68
21.	Flight Map 009-80-1, 1980 January 09	73
22.	Hodograph (1100 hrs) and Temperature Sounding (1200 hours), 1980 January 09	76
23.	Hodograph, 1980 January 09, 1700 hrs	77
24.	Flight Map 009-80-2, 1980 January 09	79
25.	Flight Map 010-80-1, 1980 Januar6 10	81
26.	Hodograph (1100 hrs) and Temperature Sounding (1130 hrs), 1980 January 10	84
27.	Flight Map 011-80-1, 1980 January 11	86
28.	Temperature Sounding, 1980 January 11, 1320 hrs	91
29.	Flight Map 013-80-1, 1980 January 13	92
30.	Hodograph (1100 hrs) and Temperature Sounding (1030 hrs), 1980 January 13	93
31.	Hodograph, 1980 January 13, 1700 hrs	95
32.	Flight Map 013-80-2, 1980 January 13	99
33.	Flight Map 078-80-1, 1980 March 18	101
34.	Hodograph (1700 hrs) and Temperature Sounding (1750 hrs), 1980 March 18	103
35.	Flight Map 079-80-1, 1980 March 19	105
36.	Hodograph, 1980 March 10, 1700 hrs	108
37.	Flight Map 080-80-1, 1980 March 20	110
38.	Hodograph (1100 hrs) and Temperature Sounding (1015 hrs), 1980 March 20	112

continued ...

LIST OF FIGURES (CONTINUED)

		Page
39.	Flight Map 081-80-1, 1980 March 21	114
40.	Hodograph (1700 hrs) and Temperature Sounding (1600 hrs), 1980 March 21	115
41.	Flight Map 081-80-2, 1980 March 21	118
42.	Flight Map 084-80-1, 1980 March 24	121
43.	Hodograph (1100 hrs) and Temperature Sounding (0915 hrs), 1980 March 24	122
44.	Flight Map 085-80-1, 1980 March 25	125
45.	Hodograph and Temperature Sounding, 1980 March 25, 1100 hrs	128
46.	Hodograph (1700 hrs) and Temperature Sounding (1630 hrs), 1980 March 25	130
47.	Flight Map 085-80-2, 1980 March 25	132
48.	Flight Map 177-80-3, 1980 June 25	133
49.	Flight Map 180-80-2, 1980 June 28	136
50.	Flight Map 186-80-1, 1980 July 04	139
51.	Hodograph (1200 hrs) and Sounding (1018 hrs), 1980 July 04	142
52.	Flight Map 187-80-1, 1980 July 05	143
53.	Hodograph (0600 hrs) and Sounding (0930 hrs), 1980 July 05	145
54.	Sounding, 1980 July 05, 1008 hrs	146
55.	Flight Map 189-80-1, 1980 July 07	149
56.	Hodograph (0600-0630) and Sounding (0520 hrs), 1980 July 07	155
57.	Flight Map 189-80-2, 1980 July 07	156
58.	Hodograph, 1980 July 07, 0700-0730	157

continued ...

LIST OF FIGURES (CONTINUED)

		Page
59.	Flight Map 189-80-4, 1980 July 07	158
60.	Flight Map 189-80-6, 1980 July 07	159
61.	Flight Map 190-80-1, 1980 July 08	161
62.	Temperature Sounding, 1980 July 08, 1200 hrs	163
63.	Flight Map 190-80-4, 1980 July 08	164
64.	Sounding, 1980 July 08, 1400 hrs	165
65.	Cutaway Diagram of Low Volume Filter Holder	169
66.	Schematic of Photoprocessor Used for Impregnating Filter Papers	171
67.	Cryogenic Trapping/Sampling Procedure for Hydrocarbon Analysis	182
68.	Glass Bottle for Calibration Mixture	187
69.	Radiation Data for 80-01-09	240
70.	Radiation Data for 80-01-10	240
71.	Radiation Data for 80-01-11	241
72.	Radiation Data for 80-01-12	241
73.	Radiation Data for 80-01-13	242
74.	Radiation Data for 80-03-18	243
75.	Radiation Data for 80-03-19	243
76.	Radiation Data for 80-03-20	244
77.	Radiation Data for 80-03-21	244
78.	Radiation Data for 80-03-24	245
79.	Radiation Data for 80-03-25	245
80.	Radiation Data for 80-06-25	246
81.	Radiation Data for 80-06-27	246

continued ...

LIST OF FIGURES (CONCLUDED)

		Page
82.	Radiation Data for 80-06-28	247
83.	Radiation Data for 80-07-04	248
84.	Radiation Data for 80-07-05	248
85.	Radiation Data for 80-07-07	249
86.	Radiation Data for 80-07-08	249

ABSTRACT

During the winter and summer of 1980, studies were undertaken in the Athabasca Tar Sands Area to obtain insight into the chemical processes that take place in the plumes from the Oil Sands plants, in particular with respect to the transformation chemistry of SO_2 and NO_x.

The importance of homogeneous gas phase reactions was reconfirmed. Oxidation of SO_2 by OH radicals could explain the SO_2 → sulphate conversion not only in July but March as well. Indications for the occurrence of aqueous phase oxidation in January and March was also obtained.

Several observations were made that would support the theory on homogeneous gas phase processes. Thus, transformatio· of NO_x to HNO_3/nitrates was tentatively identified. During the summer elevated ozone levels within the plume were observed, implying the occurrence of enhanced radical chemistry. From the observed hydrocarbon levels, a tentative OH radical concentration could be derived which in turn could explain almost all observed oxidation in March and July.

Hydrocarbons observed appeared to originate directly from the stack, possibly mixed with flare gas exhaust, but not from the (open pit) mines. Levels were low and appeared insufficient to explain the ozone bulges in the plumes, observed in the summer. One wintertime ice fog sample appeared to suggest that large amounts of emitted hydrocarbons were incorporated in the ice fog particles.

A few simple calculations were made to determine the internal consistency of the data. It appeared that during the winter very little plume dispersion occurred either horizontally or vertically. This would suggest that the Tar Sands plant emissions will be transported over a very large distance during that time of the year.

ACKNOWLEDGEMENTS

It is impossible to mention all persons who contributed to parts of this study. Major contributions were made by Mr. K.L. Grandia and his staff of pilots and technicians at INTERA Environmental Consultants, who were in charge of aircraft operations; Dr. J.M. Gray and his technicians at the Alberta Research Council, who prepared the filters and performed their analysis after exposure; Dr. O.P. Strausz and Dr. M. Selucky at the Hydrocarbon Research Centre, who gave invaluable advice and assistance in the development of the hydrocarbon analysis procedures; and Dr. H.S. Sandhu and Mr. W.D. Hume and several other staff members from the Research Management and the Pollution Control Divisions of Alberta Environment for assistance with instrumention and calibration, logistics in the field, and other general support throughout this study.

Thanks are also due to Dr. M.A. Lusis (Ontario Ministry of the Environment) and Dr. K.G. Anlauf (Atmospheric Environment Service) for instrument loans.

This research project was funded by the Alberta Oil Sands Environmental Research Program, a program established to fund, direct, and co-ordinate environmental research in the Athabasca Oil Sands area of northeastern Alberta. During the time of this study the author was employed by the Alberta Department of the Environment.

1. INTRODUCTION

Modern society has become very dependent on a steady supply of fossil fuels for energy production. The political instabilities in the major oil producing nations of the Middle East and the resulting large uncertainties in availability and pricing of crude oil in the seventies made it attractive to increase efforts towards production of crude from so-called less conventional sources including the vast Tar Sands reserves in Northeastern Alberta. From the start it was realized, however, that development in this area would have the potential for major disturbances of the relatively pristine environment in which the major deposits are located. The Alberta Oil Sands Enironmental Research Program was therefore initiated in order to assess the environmental impact of current and future development near the Athabasca oil sands deposits.

The exhaust plumes from the sands plants that upgrade the raw material to synthetic crude form one aspect of the environmental threat of the tar sands operations. In particular, these plumes are rich in sulphur oxides, largely sulphur dioxide, and to a lesser extent in oxides of nitrogen, hydrocarbons, carbon monoxide, etc. (Shelfentook, 1979). Such a dispersing plume forms a very complex, reactive chemical system of pollutants and indigeneous species. It is today well established that the major emitted species can to a large extent be oxidized into acidic species such as sulfuric and nitric acid. In this way they will lead to the formation of acidifying precipitation. Furthermore, concurrently with these transformations oxidants such as ozone and peroxyacetylnitrate can be produced.

Extensive laboratory and field work during the last decade has elucidated some of the major features of this transformation chemistry. Abundant evidence suggests that both homogeneous and heterogeneous pathways of transformation occur in the atmosphere. Homogeneous oxidation in the gas phase mainly involves reactions with OH radicals produced from photochemical reactions and hence requires near UV radiation from the sun as initiator. Aqueous phase oxidation takes place after the reactants are dissolved in cloud or aerosol droplets. The actual oxidation that follows is as yet poorly understood, but presumbably involves oxidizing species such as hydrogen peroxide (H_2O_2) and ozone, or catalyzing metal ions. It is painfully clear

from the abundance of field study results, that beyond such general features, sufficiently unique aspects are associated with each polluting source so that prediction of the actual transformation chemistry is a hazardous undertaking without an extensive body of on-site observations.

The Alberta Oil Sands Environmental Research Program (AOSERP) was initiated in order to assess the environmental impact of future development near the Athabasca oil sands deposit. As part of the atmospheric resarch component of AOSERP, early field studies were undertaken to obtain insight in the chemistry occurring in the plume from the only plant then in operation (Suncor). Some surprizing results were obtained that can be summarized as follows:

- SO_2 appeared not (or very slowly) to be oxidized during the winter, or summer nights
- An SO_2 oxidation rate of 1-3% h^{-1} during summer days was observed
- During summer days excess ozone formation at downwind locations was sometimes noticed

These observations combined seemingly indicate that only homogeneous gas phase reactions are responsible for the oxidation of SO_2, not withstanding the generally favourable conditions for aqueous phase chemistry. However, data that might support the theory on the oxidation mechanism of SO_2, such as levels of oxides of nitrogen and hydrocarbons, were not collected. This omission became more acutely clear when subsequently a chemically reactive plume model was developed, and application to the 1977 data base was attempted. (Bottenheim and Strausz, 1981).

The present field studies were, therefore, organized to try and obtain a more substantial database pertaining to the chemical composition of the air in and outside the major plumes from the oil sands plants. More specifically, the main objective of this study was further determination of the oxidation rate of SO_2 in the plumes from the Syncrude and Suncor plants and to obtain auxillary chemical data that could reinforce the suggestion that homogeneous oxidation of SO_2 took place. Furthermore, evidence of the occurrence of oxidation of NO_x to HNO_3, and a confirmation of excess ozone formation in the plume during summer afternoons would be sought.

2. OUTLINE OF THE 1980 FIELD STUDIES

The 1980 plume chemistry field studies were specifically initiated to study the potential for transformation of major emitted pollutants (SO_2 and NO_x) into acidic secondary components (H_2SO_4 and HNO_3 respectively). A small air plane was instrumented to monitor the plumes from the Syncrude, and to a lesser extent, Suncor plants, at progressively longer plume travel time under different seasonal conditions. A detailed account of the sampling periods, and all data collected can be found in the Appendix. Furthermore, auxillary surface data from a variety of other sources is included in that chapter. An outline of the sampling program and a summary of the data obtained will be presented here.

2.1 METEOROLOGICAL CONDITIONS

Three sampling campaigns were held: January 9-13, March 18-25 and June 28 - July 8. The January period was characterized by extreme cold winter conditions (typically -20° to -30° C at the surface) with strong inversions aloft. The plume conditions were generally very similar with very little vertical mixing. There were no cases with the plumes penetrating the inversion level, nor were there any cases of fumigation mixing down to the surface. On one particular day (January 10) the plume was emitted into a clearly noticeable ice fog.

The March campaign took place under more moderate, late winter conditions with surface temperatures a few degrees below freezing. Plume behaviour was again rather constant with more vertical mixing than in January, but still in a stable boundary layer. Only on March 25 was the plume sampled in a neutral boundary layer, and was there some evidence of plume fumigation.

During June/July quite different climatic conditions were encountered with typical summer type weather (largely sunny weather with some afternoon scattered cloud and surface temperatures in the mid 20°C). The synoptic conditions then ranged from stable boundary layers that resulted from nocturnal inversions to mid-afternoon convective instabilities. On several occasions plume fumigation to the surface was apparent.

2.2 IN SITU MONITORING

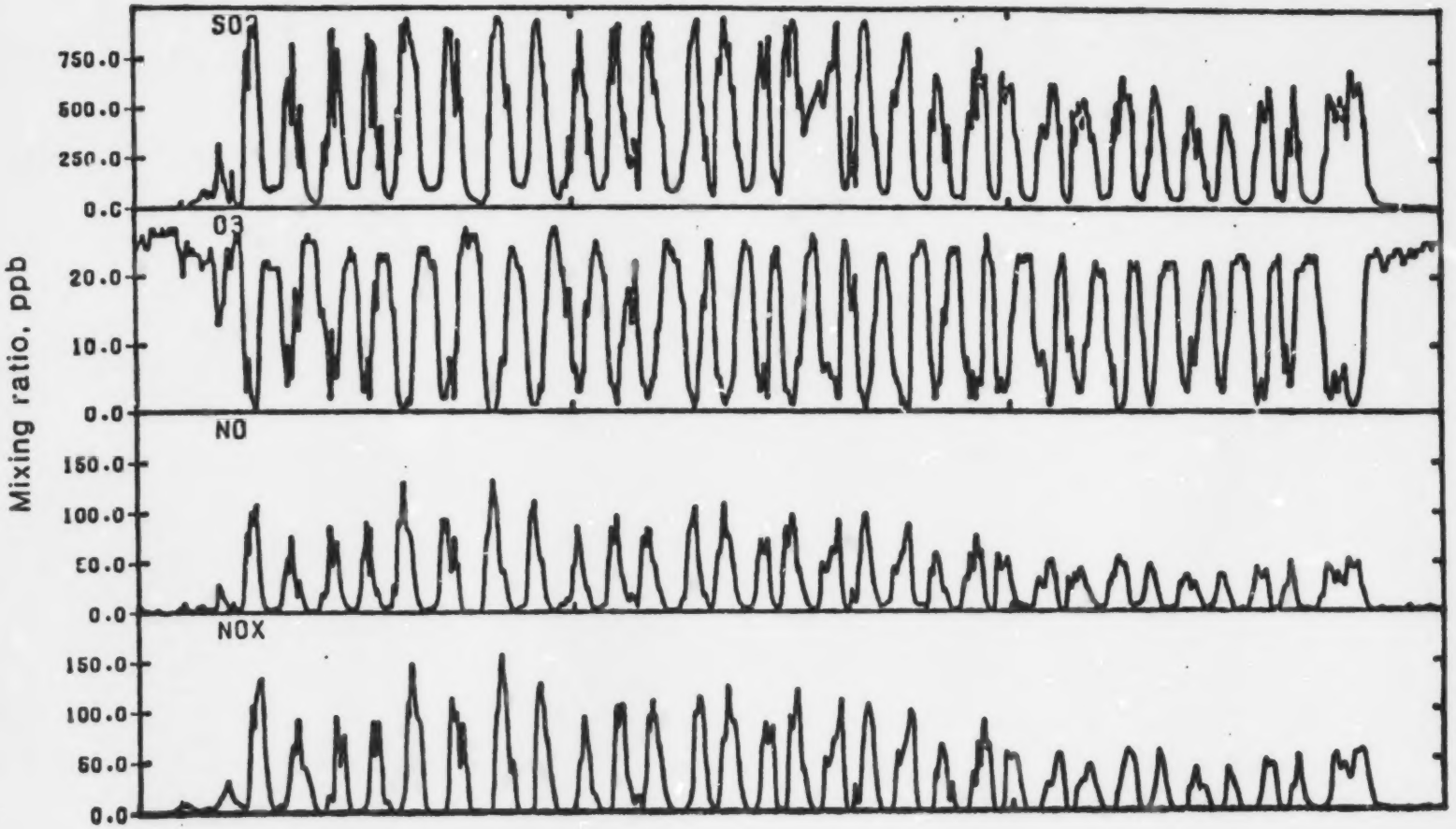
Several parameters were continuously monitored on board while traversing the plumes. It was intended to record all useful data on magnetic tape, however, for a variety of reasons such recording failed during each campaign. Hence traces from gas monitors were only obtained on backup chart recorders, while other parameters were tabulated as average values observed by the instrument operator during each flight. A list of in situ parameters thus monitored is presented in Table 1, while Figure 1 shows a representative set of chart recorder traces. Note that no radio signals were used for establishing the sampling location. The accuracy of such a procedure based on available radio signals in the AOSERP area was deemed less than could be obtained by visual observations.

The traces of the gas monitors were used for plume identification, and estimation of the SO_2/NO_x ratio. The ratio observed ranged from ca. 5:1 to 10:1 as would be expected from the emission data of the Syncrude and Suncor plant (Shelfentook 1978). On occasion, though, relatively more NO_x was observed. The SO_2/NO_x ratio was observed to change with plume travel time, as will be discussed in chapter 3.2.

Quantitatively, the maximum values for SO_2 and NO_x ranged from ca. 1 and 0.2 ppm respectively close to the chimney to below detection limit (estimated at 5 ppb each for SO_2 and NO_x) in the background air. O_3 on the other hand ranged from essentially zero at the plume centre close to the stack, to ambient levels of ca. 18, 24 and 50 ppb during January, March and July respectively. The occurrence of excess ozone levels was occasionally observed during July within the plume boundaries at ca. 15-20 miles downwind from the chimney. These results were not unexpected in view of similar observations by Lusis et al. (see Fanaki 1979b), but remain difficult to rationalize since sufficient hydrocarbons to promote excess ozone formation were not observed. Additional data on the levels of oxides of nitrogen, and the NO_2/NO ratio, would be very instructive in delineating the origin of excess ozone, but with the available instrumentation the required sensitivity could not be attained to make such measurements.

Table 1. In situ monitoring equipment.

Temperature	Rosemont 102 u2u	-50°C to 50°C	± 0.5°C
Dew Point	E.G. & G. model 137	-50°C to 50°C	±0.5°C
Atmospheric Pressure	Ball model Ex 410	0-30,000' MSL	±75'
Air Speed	Ball model Ex 210	0-200 KIAS	±2KTS
SO_2	Meloy model SA285	0.5 - 1000 ppb	±0.5 ppb
NO - NO_x	Monitor Labs, model 8440E	2 ppb - 5 ppm	± 1%
O_3	Monitor Labs, model 8410A	3 ppb - 20 ppm	± 1%
Data Acquisition	Monitor Labs, model 9400 MFE Chart Recorders		



20 MARCH 1980. 12.44-14.10 M.S.T.

Figure 1. Chart recorder traces of gas monitors during sampling of Suncor plume.

2.3 FILTER PACK COLLECTIONS

Filter packs were employed to obtain data on the average levels of particulate sulphate and nitrate, and gaseous nitric acid and sulphur dioxide. This sampling method followed identical procedures as described in detail by Lusis et al. (see Fanaki 1979a) with the following modifications.

The front part of the Swinnex filter holder was replaced by an identical part, made of Teflon, and a 3 μm pore diameter Teflon filter was used for particulate sampling. Next an extra stage was added before the filters that would collect SO_2. This extra stage was also made of Teflon, and lead to a NaCl impregnated Whatman-41 filter, which was intended to collect gaseous HNO_3. The switch to an all-Teflon front part was made to minimize potential interference with sampling HNO_3 (Stevens 1979). No specially designed isokinetic sampling tip was used, and the air was sampled at a rate of ca. 20 $l.min^{-1}$ by means of a Venturi exhaust at the end of the sampling line. The sampling rate was measured after the filter holder but before the Venturi using a Hastings mass flow meter. All exposed filters were stored in petri-dishes and as soon as possible shipped to Edmonton, where they were analyzed by ion chromatography at the Alberta Research Council.

It turned out that with the way sampling was performed, the amount of sulphate collected on the particulate filter was often barely enough for analysis purposes. It is therefore not surprizing that no detectable amount of HNO_3 was ever observed on the second filter, since the expected sulphate/nitrate (including HNO_3) ratio is larger than 1. Hence during the March and June/July campaign occasionally the air was sampled with a hivol sampler on Whatman-40 filters. On these filters one would expect to collect all sulphate particles as well as most nitrate, including gaseous HNO_3. A detailed description of filter pack design, filter preparation, and analysis, as well as the data obtained can be found in Appendix 6.3.

2.4 GRAB SAMPLING FOR HYDROCARBON ANALYSIS

Earlier field studies in the AOSERP study area indicated the possibility of homogeneous gas phase conversion of SO_2 into sulphate. Hence it was decided to collect grab samples of plume and background air during the

1980 field studies, and determine whether measureable amounts of reactive hydrocarbons were present that could stimulate such gas phase chemistry. Grab samples of air were collected in Tedlar bags, shielded from sunlight by two layers of black garbage bags. The sampling system consisted of a 1/4" stainless steel line, and the bags were filled with ram air, thus avoiding potential contamination from pumps. The grab samples were analyzed by gaschromatography (HP-5830 GC; Porapak-N for C_2 and Durapak/n-octane for C_3-C_6 hydrocarbons), usually immediately after termination of each flight at the AOSERP Mildred Lake facilities, in order to minimize potential sample deterioration.

A detailed description of the hydrocarbon analysis procedures, and the data obtained is given in Appendix 6.4.

3. RESULTS AND DISCUSSION

Field experiments outside the sheltered laboratory environment always suffer from many uncontrollable factors that severely influence the intended observations. In order to arrive at quantitative conclusions it is sometimes possible to filter out those results that are obviously biased by factors not relevant to the goals of the study. The 1980 field studies in the Tar sand area have yielded a data set that is in some respects rather sparse. Hence any quantitative conclusion to be derived in this chapter is based on a very limited amount of observations, and should be considered with caution. Yet, significant trends concerning the plume chemistry in the area could be derived.

3.1 SO_x DATA

All relevant data on SO_2 and sulphate observations obtained with filter pack sampling are presented in Table 2. It should be noted that some results from the complete data set have been deleted here (see Appendix 6.3) for the following reasons.

The data obtained in the morning of 9-1-80 and evening of 25-6-80 are ignored since they pertain to test flights only. The data at 1 mi distance for 7-7-80 as well as for the morning of 8-7-80 are not considered, since the intended estimate of SO_2 oxidation rate could not be derived due to drastic different meteorological conditions (see 3.1.3). Finally the data obtained on 10-1-80 are not considered, since the ice fog on that day caused rapid icing and hence drop of sampling flow.

As will be discussed below the SO_2 data obtained with the filter pack are reasonably consistent when compared with those obtained with the flame photometric detector (Meloy-285). However, a comparison between filter pack and hivol data shows large inconsistencies, see Table 3. The ratio of flow rates would suggest that the hivol samples should collect ca 50-80 times as much material as the filter pack sampler, while for SO_2 the observed ratio is consistently less than 10. Since the method of determination of hivol flowrate was rather crude (based on the pressure drop over the total hivol filter assembly) part of this inconsistency could be due to an overestimate of this flow rate. More serious however, is the fact that no consistent pattern emerges from a comparison of the hivol over filterpack ratio for material

Table 2. $SO_4^=$/ total-S ratio as determined by filter pack sampling during 1980 plume chemistry field studies.

Date	Source[a]	Distance (mi)	Time[b] (MST/MDT)	Wind[c] (mph)	Temp (°C)	Dew Point (°C)	Plume Travel Time (min)	$SO_4^=$/total-S[d] (%)	Rate (%h^{-1})
9-1-80	Sy	4	18:17:18:38	15-17	-23	-	15	14.7	
		6	17:55-18:15				23	17.9	29
11-1-80	Sy	2	13:57-14:19	10-12	-26	-	11	18.3	
		8	14:30-15:02				44	26.4	19
		15	15:40-16:15				82	17.0	-19
	Su	10	15:05-15:31				55	5.5	
13-1-80	Sy	2	11:06:11:30	12-14	-20	-	9	8.8	
		10	11:39-12:11				46	13.3	8.2
		20	12:16-12:51				92	10.4	4.3
		30	15:45-16:18				138	13.4	-4.4
18-3-80	Sy	2	15:45-16:51	14-16	-3	-	8	10.7	
	Su	2	17:02-17:35				8	3.2	
19-3-80	Su	2	17:28-18:08	6-8	-2	-	17	7.5	
		11	18:20-19:16				94	4.2	-2.7
20-3-80	Sy	2	11:12-12:30	3-5	-6.5	-	30	6.4	
	Su	2	12:38-14:10				30	1.6	
21-3-80	Sy	2	12:25-13:51	3-5	-4.5	-	30	7.7	
		8	14:02-15:31				120	2.5	-3.6
		20	17:15-18:49				300	2.1	-0.1

continued

Table 2 (concluded)

Date	Source[a]	Distance (mi)	Time[b] (MST/MDT)	Wind[c] (mph)	Temp (°C)	Dew Point (°C)	Plume Travel Time (min)	$SO_4^=$/total-S[d] (%)	Rate ($\%h^{-1}$)
24-3-80	Sy	2	10:13-11:30	16-18	-3	-	7	1.2	
	Su	2	11:40-13:15				7	1.1	
25-3-80	Sy	2	10:10-11:10	9-11	-7	-	12	2.6	
		6	13:14-14:00				60	3.8	1.5
		25	14:25-15:20				250	2.9	-0.3
28-6-80	Sy	1	12:50-13:45	N.D.[e]	17	6	N.D.	1.8	
	Su	1	14:20-15:03		17.5	6		2.1	
4-7-80	Sy	1	10:10-11:11	4-6	21.5	8.5	12	1.3	
		5	11:20-12:25		19.5	8	60	3.4	2.7
5-7-80	Sy	1	08:00-08:35	8-10	19	11	7	0.8	
		5	06:50-07:55		18.5	11	33	1.2	0.9
		35	05:15-06:45		20	11.5	233	0.7	-1.5
7-7-80	Sy	6	05:30-06:30	8-10	16	4.5	40	1.5	
			10:40-11:25		18	6	40	1.1	
			14:45-16:00		21	12	40	5.7	
			18:38-19:28		22.5	10.5	40	13.6	

NOTES:
a Sy = Syncrude, Su= Suncor
b MST in January, March; MDT in June, July
c No inflight measurements were made; data derived from Fort McMurray Airport soundings.
d Accuracy is estimated at 25%
e N.D. = no data available.

Table 3. Comparison of apparent hivol versus filterpack collection efficiencies.

Date	Time (LST)	Ratio hivol/filter pack			
		Flowrate	Particulate S (2)	SO_2 as SO_4 (3)	(2)/(3)
20-3	11:12-12:30	54	42	9.6	4.4
	12:38-14:10	56	32	8.9	3.6
21-3	12:25-13:51	51	12	4.9	2.5
	14:02-15:31	51	26	3.4	7.5
24-3	10:13-11:30	54	27	2.8	9.5
	11:40-13:15	54	18	3.3	5.4
25-3	10:10-11:10	59	16	3.2	5.0
	13:14-14:00	57	15	4.1	3.6
	14:25-15:20	57	16	4.4	3.7
28-6	14:20-15:03	67	5.9	3.2	1.8
4-7	10:10-11:11	67	12	7.4	1.7
	11:20-12:25	67	6.7	4.8	1.4
5-7	05:15-06:45	76	12	8.9	1.3
	06:50-07:55	76	13	13.	1.0
	08:00-08:35	76	13	6.9	1.9
7-7	05:30-06:30	61	15	8.1	1.9
	10:40-11:25	58	11	6.5	1.8
	14:45-16:00	58	5	2.9	1.7
	18:38-19:28	67	12	3.7	3.4

collected on the particulate and SO_2 filters respectively. Not only is the ratio for particulate collection consistently higher than that for SO_2, but moreover this difference in collection efficiency is highly variable (see last column). It is noteworthy that (with one exception) this difference is smaller for the June/July cases than for the March cases. In March flow through the hivol sampler was effected mainly as a result of ram air pressure (a Venturi - exhaust was used at the exit of the sampler, but its effect is believed to be minor in this respect), while during the summer study a hivol blower was installed behind the hivol filter assembly. In view of these problems with the hivol sampler it was decided not to use the hivol data for evaluation of SO_2 / SO_4 ratios since this would require a detailed analysis of the variations of collection efficiencies on the different filters. Such a analysis appears impossible with the limited data at hand.

Two independent methods were employed to determine SO_2 levels in the plume. Filter packs registered the average concentration of SO_2 and sulphate at each sampling location. Concurrently a flame photometric detector (FP-analyzer) recorded instantaneous SO_2 levels, thus showing the plume profile. Intergration of the surface under the curves yields an independent estimate of the average SO_2 concentration. A comparison of the two methods is presented in figures 2 and 3 for winter and summer data respectively. Slightly higher levels from the FP analyzer than the filter pack were observed during the winter. Although the scatter is rather large, such a trend concurs with similar observations elsewhere (Anlauf, Atmospheric Environmnet Service, Downsview, Ontario. Personal communication, 1981). It could be concluded that the collection efficiency for SO_2 by Whatman-41 filters, impregnated with K_2CO_3/glycerol is somewhat less than total at low temperatures. However, the deviation is small, and combined with the data scatter, is most likely not significant. Hence it is concluded that the filter pack data are as reliable as can be expected from such experiments.

Unfortunately a similar comparison for the summer data is much worse, and shows the opposite trend,viz. more SO_2 was found on the filters than suggested by the FP analyzer. This observation is almost certainly due to less reliable data from the FP analyzer. (The summer study used a different instrument that caused several problems not encountered during the winter).

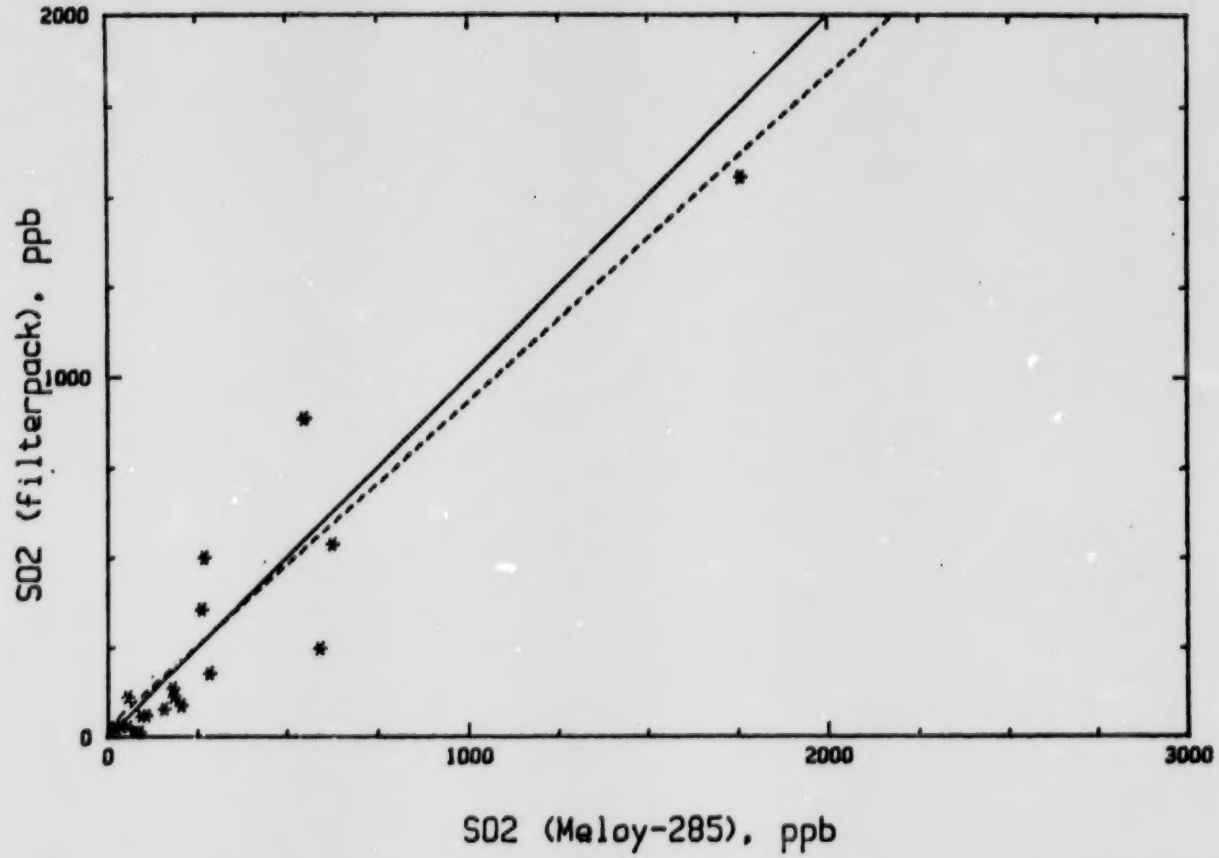


Figure 2. Comparison of integrated SO_2 data from filterpack and flame photometric sampling (Meloy-285). _____: 1:1 ratio (perfect correction), _____: least square regression of data points. Data for January and March studies.

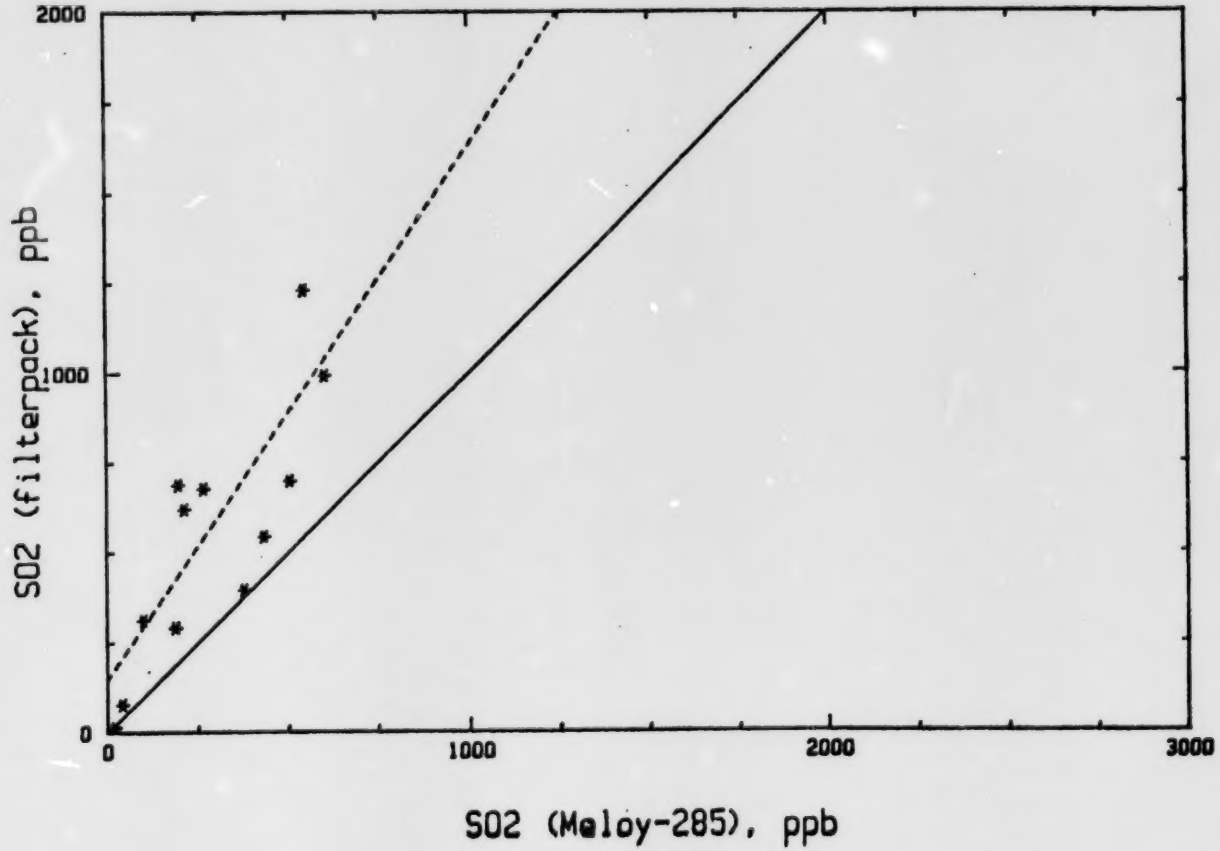


Figure 3. Comparison of integrated SO_2 data from filterpack and flame photometric sampling (Meloy-285). _____: 1:1 ratio (perfect correlation), _____: least square line regression of data points. Data for June/July study.

3.1.1 Percent Sulphur as Sulphate

It can be seen in Table 2 that the percent sulphur as sulphate (the SO_4/total-S ratio) appears to increase markedly during some of the January samplings, and less so during one March and one July sampling with plume travel time. Otherwise, several cases of a decrease in the SO_4/total-S ratio is observed. A graphical representation of these data is presented in Figure 4. Although the experimental error limits are believed to be large, the observed variations are too large to be due to such errors alone, and hence are considered significant. On several occasions Newman and co-workers have observed a similar decrease in the SO_4/total-S ratio at longer plume travel time when sampling power plant plumes in the United States (Newman et al. 1975a, 1975b; Forrest and Newman 1977). These workers also found evidence that sulphate particles actually dropped out of the plume. Similarly, Barrie (1980) observed the phenomenon of "snowout" from the Suncor plume during winter field studies in the AOSERP study area. Although no direct evidence for such a loss of sulphate was observed during the 1980 studies, most likely it is the explanation for the decrease in the SO_4/total-S ratio.

Worth noticing is the generally large percentage sulphur as sulphate in the Syncrude plume, particularly during January. Lusis et al. (in Fanaki 1979a,b) observed an average level of only ca. 1-2% in the Suncor plume during their field studies. At first thought one is tempted to conclude that the observation on the Syncrude plume is due to incomplete collection of SO_2 on the filters (see the discussion above). However, one sampling of the Suncor plume was made in January, and it shows a SO_2/total-S ratio reasonably in agreement with the data from Lusis et al. Subsequently during March and June, time was devoted to a more determined comparison between Syncrude and Suncor and often the initial SO_4/total-S ratio was observed to be higher in the Syncrude than the Suncor plume. (see Table 2, data for 18-3,20-3,24-3,28-6) The reason for this fact is not clear, but it should be caused by differences in plant operations between Syncrude and Suncor. It is noteworthy that the data suggest that this effect is more pronounced at lower temperatures.

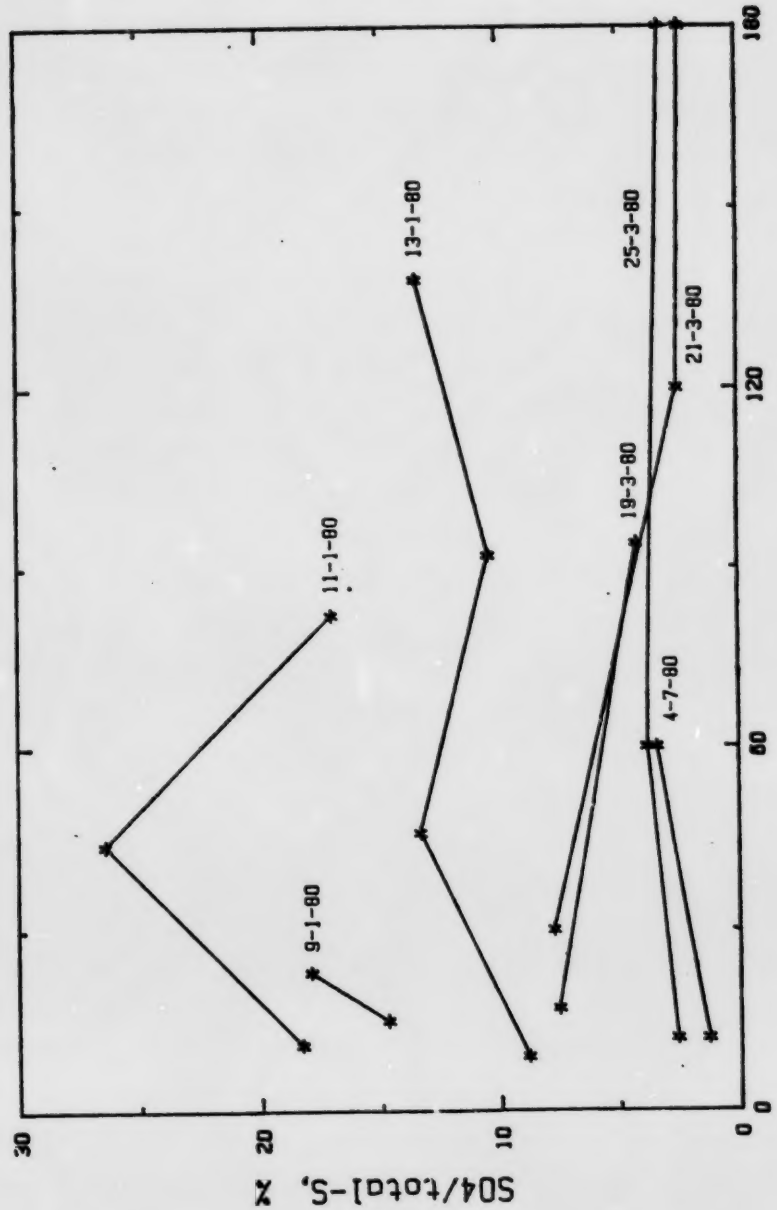


Figure 4. Ratio $SO_4^=$/total-S as function of plume travel time, determined from filterpack data.

3.1.2 Transformation of SO_2 to Sulphate During the Winter

Contrary to the results obtained by Lusis et al. in 1977, when studying the Suncor plume, the data from the 1980 field studies suggest that some transformation of SO_2 to sulphate does occur during the winter in the Syncrude plume. The largest apparent conversion was observed during a very cold early night flight (January 9), and hence if these data do indeed mean an oxidation of SO_2 to sulphate, then a photochemically induced process is excluded. Furthermore, an increase in the SO_4/ total-S ratio is only observed during the first hours of plume travel. In particular, the only increase in this ratio observed during the March sampling period coincides with the only occasion that the second observation point was reached by the plume after less than one hour of travel. (However in this particular case the apparent transformation can also be explained on the basis of homogeneous oxidation by OH radicals, as will be outlined later). Finally all increases in the SO_4/total-S ratio were observed on days with temperatures below 0°C. The magnitude of this increase seems to correlate inversely with temperature, with the largest increase occurring at the lowest temperatures. These observations are in agreement with the theoretical treatment of Freiberg (1976) concerning the iron catalyzed oxidation of SO_2 in a power plant plume. It might be added here that analysis of stack particulates from the Syncrude chimney shows that iron is usually the most abundant metal present (McKay, Syncrude Canada, Fort McMurray, Alberta. Personal communication, 1980).

One might argue that the observed changes in the SO_4/total-S ratio were due to other factors not related to transformation. Thus, the initial increase in the ratio followed by subsequent decrease might be due to the opposing effects of more effective collection of SO_2 at lower average concentration and decreased importance of sulphate fall out at longer travel times. Such an explanation cannot be ruled out, but seems rather coincidental. Furthermore, it would suggest a much larger problem with the SO_2 collection efficiency than seems apparent and finally seems at odds with the "normal" SO_4/total-S ratio observed during January in the Suncor plume.

3.1.3 Transformation of SO_2 to Sulphate During the Summer

The data collected on July 4, 7 and 8 were intented for an analysis of summer daytime transformation of SO_2. However, the absence of an apparent

conversion during July 7 and 8 is probably due to other factors than the absence of oxidation. There is good evidence that the two sampling periods occurred different meteorological regimes. Thus the first sampling, which on both days took place between 10 and 11 A.M., concurred with the break up of the nighttime inversion and the plume did not yet touch the surface, while the second sampling occurred well after the onset of fumigation. Pertinent temperature profiles are not available, but two other pieces of information substantiate this observation. Firstly, on both days the second sampling location was closest to the chimney and yet the amount of sulphur collected on the filters, as well as the maximum SO_2 concentration indicated by the FP analyzer, was substantially lower than found during the first sampling. Secondly, during these field studies it was observed that acetylene (C_2H_2) levels generally indicated plume dilution and stability. Thus, markedly elevated C_2H_2 levels were usually observed after relatively short plume travel time (< 1 hour) when little plume dilution would be expected, viz. in the winter or at very early morning hours in the summer, at low wind speeds. On both July 7 and 8, C_2H_2 levels were substantially higher during the first sampling period than the second, while on July 4 the C_2H_2 levels were of comparable order of magnitude, and higher at the observation point closest to the chimney (see Table 4).

The data obtained on July 4 suggest a transformation rate of SO_2 of 2.6% h^{-1}. Such a rate is entirely in line with many other field studies (for recent work see Atmospheric Environment, Vol.15, no. 10-11, 1981). It is also in agreement with the data reported by Lusis et al. for the Suncor plume. During the very early morning flights of July 5 and 7, all sampling occurred also in the same meteorological regime, viz. before inversion break-up (see C_2H_2 levels, Table 4) but no significant change in SO_4/total-S ratio was observed as function of plume travel time. Coutrary to the observations in the winter, these data then would appear to suggest that photochemically initiated oxidation of SO_2 occurred in the summer. It will be shown in section 3.3 that the hydrocarbon data obtained on July 4 support this conclusion. Other circumstantial evidence was obtained as well in the form of elevated ozone levels within the plume boundaries at distances of more than 10 miles from the chimney (Section 3.2)

Further evidence for photochemical oxidation of SO_2 can be inferred from the data obtained at ca. 6 miles from the Syncrude stack on July 7. In

Table 4. C_2H_2 levels during July, 1980.

Day	Time (MDT)	Distance from Syncrude chimney (mi)	C_2H_2 (ppbC)
4-7-80	10:30	1	2.1
	11:50	5	1.1
	12:50	Background	0.4
5-7-80	06:00	35	20.7
	07:00	5	10.3
	08:00	1	22.9
7-7-80	06:00	6	10.9
	07:30	Background	1.6
	11:00	6	9.3
	12:00	1	1.6
	15:00	6	0.7
	18:30	6	0.6
8-7-80[a]	11:00	6	40.3
	11:45	1.5	11.0
	14:00	15[b]	1.2
	15:30	8[b]	2.6

a These samples were analyzed on 11-7-80 in Edmonton.

b Suncor plume sample; distance from Suncor chimney.

this case the two samplings in the morning showed a much lower $SO_4^=$/total-S ratio than the afternoon samplings. Such a result would be expected from theoretical calculations (Bottenheim and Strausz, 1979). However, this result is rather less convincing in view of the fact that the morning samplings occurred before plume fumigation in contrast with the afternoon sampling. Consequently no dry deposition of SO_2 could have occurred in the morning, but the afternoon plume might well have suffered some SO_2 depletion due to this effect, hence increasing the apparent $SO_4^=$/total-S ratio (the dry deposition rate for SO_2 is known to be almost an order of magnitude higher than that for $SO_4^=$, see Denison et al, 1979).

3.2 NO_x AND O_3 DATA

Although the main subject of this study was the evaluation of the SO_2 → sulphate chemistry, it was intended to gain insight of the potential NO_x→nitrate conversion as well. To this end a chemiluminesce NO_x detector continually recorded NO_x and NO levels, while the filterpack was designed to determine particulate nitrate as well as nitric acid. However, as mentioned in Chapter 2, the filter pack appeared to be able to just determine particulate sulphur levels. Since nitrate levels should be expected to be lower than sulphate levels in view of the emission data from the plants (Shelfentook, 1978), no useful data on NO_3^-/HNO_3 could be obtained with this sampler. Some indication on total nitrate was obtained from the particular filter of the hivol sampler, however.

All relevant NO_x and total nitrate data are presented in Table 5. The NO_x data were derived from integration of the area under the stripchart recorder traces of the NO_x detector, employing the same procedure as used for SO_2 (section 3.1). The NO_x data were divided by the concurrent SO_2 data from stripchart recorder integration, while the total nitrate levels were divided by concurrently obtained sulphate levels on the same particulate filter. This method of presenting the data was chosen to partially eliminate the effects of plume dispersion and collection efficiency of the hivol sampler on the apparent concentration variations.

Examination of the data of Table 5 shows a large variation in the trend of the NO_x/SO_2 ratio. The data for 11-1, 13-1 and 25-3 show a decrease with distance from the plume, while on 9-1 (evening), 19-3 and 21-3 an

Table 5. NO_x/SO_x data during 1980 plume chemistry field studies[a]

Date	Source	Time (MST/MDT)	Distance (mi)	Wind (mph)	Temp (°C)	Dew Point (°C)	Plume Travel Time (min)	NO_x/SO_2[b]	$NO_3^-/SO_4^=$[c]
9-1-80	Su	10:43-11:03	8	-	-	-		.096	-
	Su	11:05-11:26	8					.113	-
	Sy	18:17-18:38	4	15-17	-23	-	15	.197	-
	Sy	17:55-18:15	6				23	.382	
11-1-80	Sy	13:57-14:19	2	10-12	-26	-	11	.188	-
		14:30-15:02	8				44	.086	-
		15:40-16:15	15				82	.061	-
	Su	15:05-15:31	10				55	-	-
13-1-80	Sy	11:06-11:30	2	12-14	-20	-	9	.231	-
		11:39-12:11	10				46	.231	-
		12:16-12:51	20				92	.125	-
		15:45-16:18	30				138	-	-
18-30-80	Sy	15:45-16:51	2	14-16	-3	-	8	.458	-
	Su	17:02-17:35	2				8	.246	-
19-3-80	Su	17:28-18:08	2	6-8	-2	-	17	.261	-
		18:20-19:16	11				94	.590	-
20-3-80	Sy	11:12-12:30	2	3-5	-6.5	-	30	.096	.026
	Su	12:38-14:10	2				30	.086	.055

...continued

Table 5. (continued)

Date	Source	Time (MST/MDT)	Distance (mi)	Wind (mph)	Temp (°C)	Dew Point (°C)	Plume Travel Time (min)	NO_x/SO_2 [b]	$NO_3^-/SO_4^=$ [c]
21-3-80	Sy	12:25-13:51	2	3-5	-4.5	-	30	.100	.048
		14.02-15:31	8				120	.144	.079
		17:15-18:49	20				300	.300	-
24-3-80	Sy	10:13-11:30	2	16-18	-3	-	7	.154	.040
	Su	11:40-13:15	2				7	-	.137
25-3-80	Sy	10:10-11:10	2	9-11	-7	-	12	.157	.037
		13:14-14:00	6				60	.076	.105
		14:25-15:20	25				250	-	.205
28-6-80	Sy	12:50-13:45	1	N.D.	17	6	N.D.	-	-
	Su	14:20-15:03	1					-	.62
4-7-80	Sy	10:10-11:11	1	4-6	20	8	12	-	.28
		11:20-12:25	5				60	-	.39
5-7-80	Sy	08:00-08:35	1	8-10	19	11	7	-	.28
		06:50-07:55	5				33	-	.39
		05:15-06:45	35				233	-	.39
7-7-80	Sy	05:30-06:30	6	8-10	16	4.5	40	-	1.18
		10:40-11:25	6		18	6	40	-	.29
		14:45-16:00	6		21	12	40	-	.39
		18:38-19:28	6		22.5	10.5	40	-	.52

... continued

Table 5. (concluded)

Date	Source	Time (MST/MDT)	Distance (mi)	Wind (mph)	Temp (°C)	Dew Point (°C)	Plume Travel Time (min)	NO_x/SO_2 [b]	$NO_3^-/SO_4^=$ [c]
8-7-80	Su	15:30-15:46	3.5	N.D.			N.D.	-	.35
		15:50-16:10	8					-	.46

NOTES:

a see Table 2 for notes on columns 1-8

b Ratio determined from integration of total area under NO_x and SO_2 chart recorder traces, expressed as molar ratio (January and March only).

c Ratio determined from total moles obtained on hivol particulate filter (Whatman-40) (March and June/July only).

increase was observed. Inspection of the stripchart recorder data suggests problems with locating the plume on 21-3 as well as separating the Syncrude plume from the Suncor plume (see also remarks in Table XX, Appendix 6.3). These problems were probably due in part to the very low windspeed. Hence, it appears reasonable to downgrade the importance of the results of that day.

The difference in the NO_x/SO_2 trend appears to correllate with the time of day that the observations were made. Thus, the data for 11-1,13-1 and 25-3 were obtained during daylight hours, while the data for 9-1 and 19-3 were obtained after sunset. Since dry deposition processes are excluded during all winter monitoring periods, one is tempted to speculate that the day time conversion of NO_x is faster than that of SO_2, but after sunset no or little conversion of NO_x takes place, while the SO_2 conversion continues. Such a qualitative picture would reinforce the deduction that some SO_2 conversion is due to non photochemically activated processes, in contrast to NO_x conversion. Without data on nitrate levels this deduction on winter time NO_x conversion has to be considered as speculative at this time.

The trend in NO_3/SO_4 ratios is much more consistent. At all times this ratio was observed to increase with distance from the stack (21-3,25-3,4-7,8-7). This observation is quite remarkable since at all times more SO_2 is present than NO_x. All these samplings occurred during daylight hours and hence would suggest that nitrate formation is much more efficient than sulphate formation during that time of the day. A similar conclusion is obtained from the data for 7-7, where it is seen that progressively during the day, with increase in photochemical activity, the NO_3/SO_4 ratio increases at a relatively constant distance from the stack. In this respect it has to be mentioned, that the results for the first sampling during that day (5.30-6.30) appear to be quite anomalous. The ratio observed was much larger than observed at any other day, due to an anomalous high level of nitrates.

In section 3.1 it was observed that the Syncrude plant appeared to emit more sulphur in the form as sulphate than the Suncor plant. From the data of Table 5, it is possible to estimate the same effect with respect to nitrate-nitrogen for only one day, i.e. 20-3. Using the formula

$$\frac{NO_3}{NO_x + NO_3} = \frac{NO_3/SO_4}{NO_x/SO_2 \cdot SO_2/SO_4 + NO_3/SO_4} \qquad (I)$$

and assuming $SO_2/SO_4 \sim$ total-S/SO_4, a comparison between percentage nitrate-nitrogen shows 1.7 and 1.0% for Syncrude and Suncor respectively. This result indicates that the difference between the two plants is probably not significant as far as nitrate-nitrogen emission is concerned. Moreover the levels appear to be quite low. On other days that a direct comparison between the Syncrude and Suncor plumes was attempted, the data set is not complete. Hence a real comparison of nitrate-nitrogen emission is not possible, but the partial dataset, either the NO_x/SO_2 (18-3) or NO_3/SO_4 (24-3) ratio, shows identical trends as for 21-3, thus supporting the conclusion reached here.

It would be possible to make a more quantitative estimate of NO_x-nitrate conversion rates from the data of Table 5, assuming strictly first order kinetics, with the formula

$$\text{Rate , \% } h^{-1} = - \frac{\Delta \ln \frac{NO_x}{NO_x + NO_3}}{\Delta t} \times 60 \times 100 \qquad (II)$$

Using data for NO_x/SO_2 and NO_3/SO_4 from Table 5, as well as SO_4/total -S $\sim SO_4/SO_2$ from Table 2, and reworking equation II to

$$\text{Rate, \% } h^{-1} = - \frac{\Delta \ln \frac{NO_x/SO_2}{NO_x/SO_2 + NO_3/SO_4 \cdot SO_4/S}}{\Delta t} \times 60 \times 100 \qquad (II)$$

the conversion rate can be calculated for the interval between the first and second sampling on March 21 and 25. The resulting rates are - 1.5 and 5.6%h^{-1} for the two days respectively.

Unfortunately no data for NO_x are available for the June/July study period, as mentioned before. Examining the data for NO_x/SO_2 for the

January and March campaigns, it appears, that the NO_x/SO_2 ratio during the summer should have been of the order of 0.05-0.1 (the ratio should be somewhat smaller than in the winter due to more active gas phase chemistry in the summer). Using these numbers as limiting values, and the NO_3/SO_4 as well as SO_4/total-S data for July 4, one estimates a conversion rate for NO_x-NO_3 for that day between 11.1 and 20.6 % h^{-1}. Such a rate is entirely in agreement with the estimated conversion rate of 2.7% h^{-1} for the SO_2 → sulphate oxidation, assuming that both the NO_x and SO_2 conversion is mainly due to oxidation by OH radicals.

It was intended to derive additional information on the NO_x chemistry from the NO and O_3 data, in particular with respect to the question whether the photostationary state between NO, NO_2 and O_3 appeared to hold during summer and winter. Unfortunately this was not possible with the data at hand due to the need to use stripchart recorder data that are not synchronous for NO, NO_x and O_3. The winter time data for O_3 are rather unspectacular. They show an almost total disappearance when sampling inside the plume at distances within 10 miles from the chimney as expected, due to titration by emitted NO. The ozone levels outside the plume were found to vary very little from day to day. Seasonally, however, the ozone level showed a variation, with an average ozone level at a remote continental site of ca 18, 24 and 50 ppb during January, March and June/July respectively. These levels are remarkably close to those, estimated theoretically in a earlier study (Bottenheim and Strausz, 1980).

On July 7 and 8 special flights were made to search for so-called "ozone bulges" in the confines of the plumes at distances a few hours travel time from the chimney. On both occasions clear cases of excess ozone were observed. The buildup of excess ozone in the Syncrude plume as observed on July 7 is summarized in figures 5-7. Although these Figures show only one plume transversal, actually in all cases several transversals back and forth were made to confirm the observed excess ozone. The observation of excess ozone serves as further evidence for photochemical activity during the summer in the Tar sands area. However it is not immediately clear how to explain these observations as will be discussed in the next section.

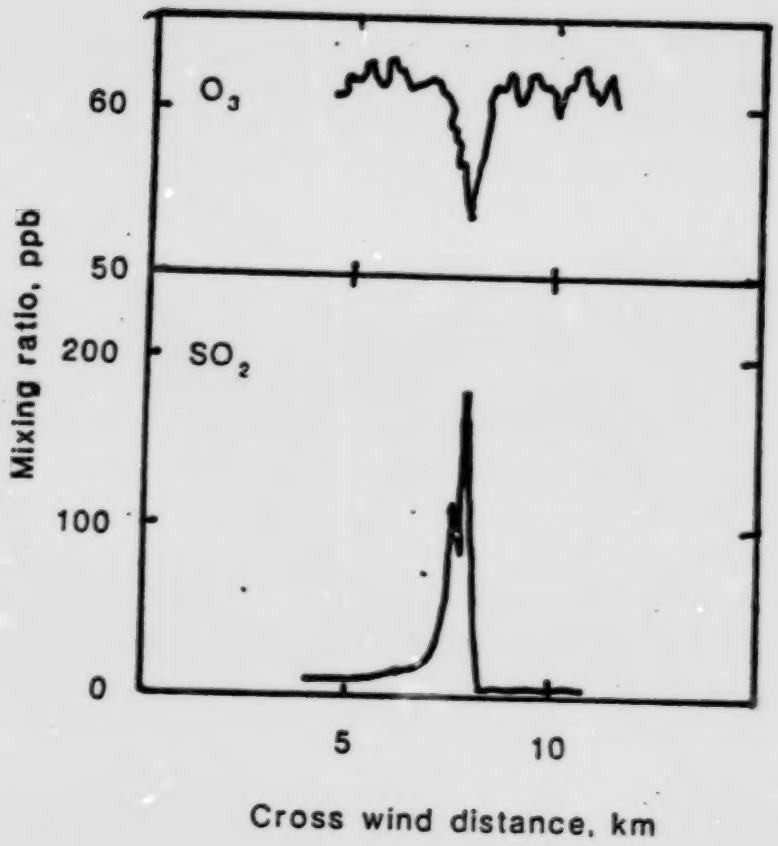


Figure 5. Cross wind plume profile, 1.5 milesfrom Syncrude stack. 7 July 1980, 13:45 MDT.

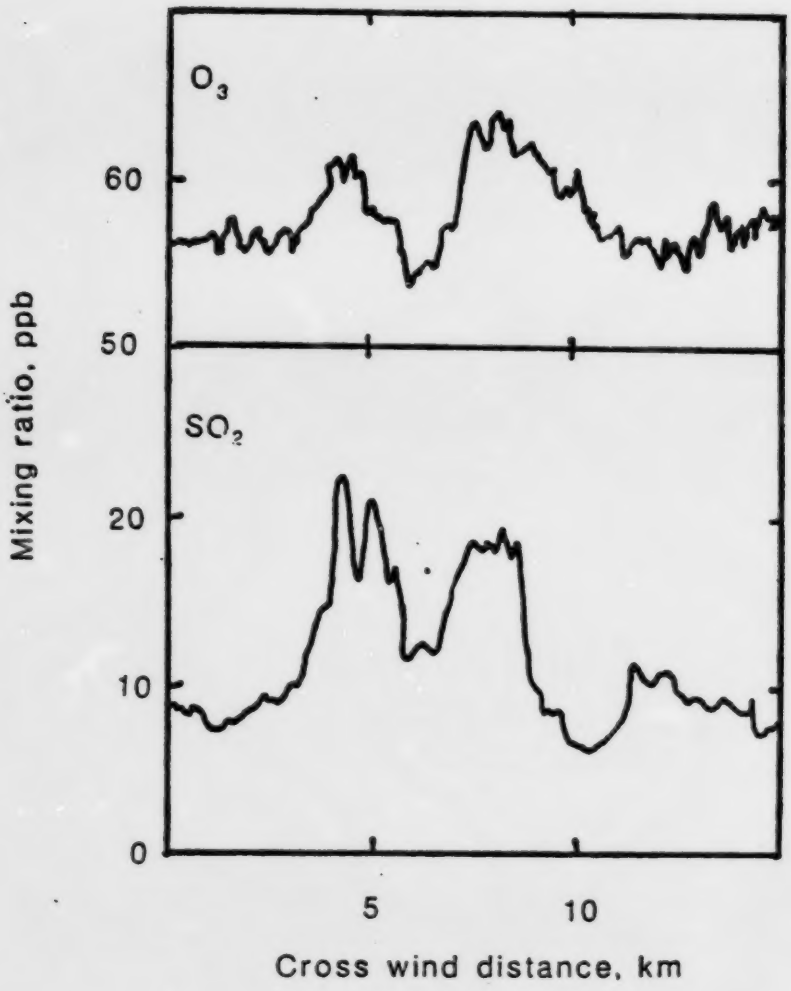


Figure 6. Cross wind plume profile, 12 miles from Syncrude stack. 7 July 1980, 14:10 MDT.

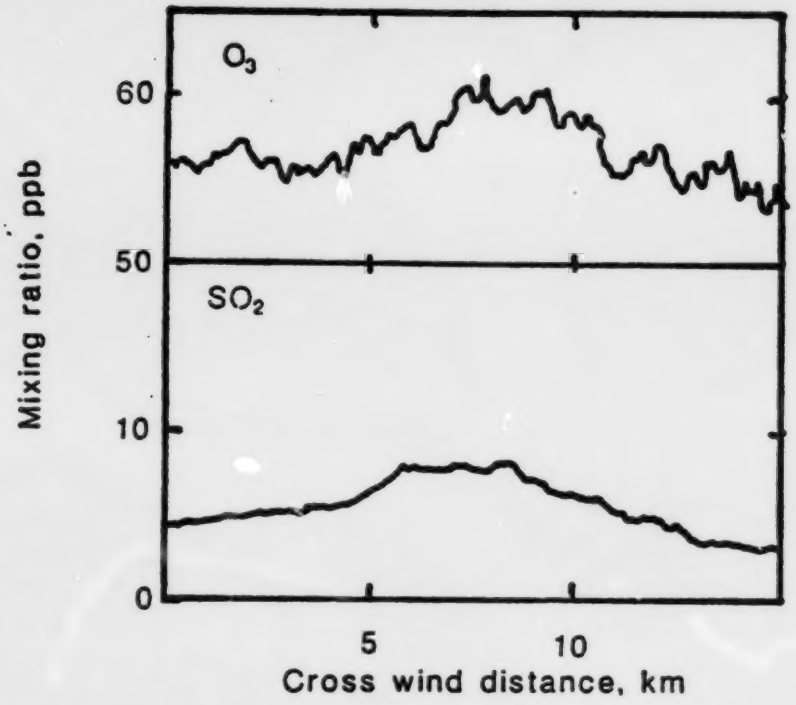


Figure 7. Cross wind plume profile, 20 miles from Syncrude stack. 7 July 1980, 14:20 MDT.

3.3 HYDROCARBONS

A major result of the 1977 field studies, as far as plume chemistry in the AOSERP study area is concerned, was the strong indication that SO_2 oxidation in plumes from the Suncor stack appeared to be photochemically initiated. With the data at hand it was not posssible to deduce whether the atmospheric composition was actually conducive to homogeneous oxidation chemistry of SO_2. Thus, the theory on homogeneous gas phase oxidation of SO_2 in a plume normally assumes that such reactions are due to the mixing of an SO_2/NO_x rich plume with polluted ambient air which contains the ingredients to activate the oxidation process. However, one would suspect the ambient air in the AOSERP study area to be very clean, and hence not containing sufficient material to cause very effective homogeneous oxidation of SO_2. It was therefore considered of paramount importance to obtain insight into the levels of hydrocarbons, present in the plumes as well as ambient air, in the AOSERP study area.

Resources limited this study to determination of C_2 -C_5 hydrocarbons; these data are compiled in Appendix 6.4. The first unmistakable conclusion to be drawn is that, as expected, the ambient air in the area is very clean, with detectable hydrocarbons limited to low levels of paraffinic compounds only, predominantly ethane and acetylene; such values are very comparable to observations elsewhere (Chameides and Cicerone, 1978; Cronn and Robinson, 1979). On the other hand within the plume boundaries (as determined by the Meloy-285 SO_2 detector) often substantially larger amounts of hydrocarbons were observed. The origin of these hydrocarbons, although obviously from the oil sands plants, could not be clearly established (more than 90% were paraffins, indicating a petrochemical origin. See e.g. Sexton and Westberg, 1979). Possible sources would appear to be evaporation from the (open-pit) mines, the flare stacks of the plants, and the main stack itself.

Two samplings were performed directly over the open pit mines. The sampling of March 25 (Table xx, number 4) showed very high levels of hydrocarbons, but the helicopter sampling of May 11 indicated only very moderate, i.e. twice the expected ambient levels. Besides the difference in airborne platform, the only apparent difference between the two samplings was that the March 25 sampling took place almost directly downwind from the stack,

while the May 11 sampling occurred more to the side of the plume. Coupled with the larger plume rise at the later date, it seems likely that the March 25 sampling was influenced by the plume itself, and the May 11 sampling not. Hence evaporative emission from the mines is not the origin of in-plume hydrocarbons. Interestingly, the relative levels of hydrocarbons in the plume appear to be rather different from those obtained when tar sand samples are degassed in a laboratory setting. In the latter case large amounts of neopentane are obtained, (Montgomery, Hydrocarbon Research Centre, Edmonton, Alberta. Personal communication, 1980) while the hydrocarbon mix in the plume does not show any trace of this compound (Note in Table xx that neopentane and 1-butene are not separated on the Durapak GC column; subsequent analysis of random samples on a Porapak -Q colum, however, showed invariably that the relevant peak was exclusively due to 1-butene).

Whether the plume hydrocarbons are actually due to main stack emission or flare stack emission, is not clear. Reported hydrocarbon levels from Suncor emission data would suggest low levels in the main stack emission. On the other hand the helicopter samplings of May 11, which were taken directly over the chimney itself, show very large levels of hydrocarbons. Since no SO_2 data are available for these samples it is not possible to determine the SO_2/ hydrocarbon ratio in these samples, and hence deduce the hydrocarbon levels emitted. It should be mentioned that since these samples were obtained without the benefit of an SO_2 analyser, plume boundaries had to be estimated from the smell of the air in which the helicopter was flying. The samples are therefore undoutedly diluted with the ambient air surrounding the exhausted plume. This air, on the other hand, must have contained hydrocarbons emitted by the not to distant flare stack.

The data for 10-1-80 are curious. As was mentioned earlier the filterpack, as well as in situ monitoring data are of little use for that day since the presence of ice fog caused rapid icing and hence complete blockage of the sample lines. However, bag samples for hydrocarbon analysis were obtained. Analysis results for successive gas chromatography runs of air from the same air sample, are presented in Table 6. It appears that with age of the sample the mixing ratio of the C_2 and C_3 components increases drastically. The C_4 and C_5 components on the other hand, although high in comparison with other days, seem to be stable.

Table 6. Light hydrocarbon mixing ratios in plume air sample collected on 10-1-80, 3 miles from Syncrude stack under ice fog conditions.

GC run	1	2	3
ethane } ethylene	25.3[a]	42.	65.
acetylene	5.7	7.3	7.6
propane	89.5	322.	1150.
propene	4.9	17.4	28.2
i-butane	12.7	8.5	10.3
n-butane	16.1	17.5	16.4
1-butene	T	5.8	6.2
i-butene	--	--	--
t-2-butene	--	--	--
i-pentane	n.a.[b]	13.6	11.5
n-pentane	n.a.	8.7	8.0
cyclopentane	--	--	--
1-pentene	--	--	--
2-m-pentane			
3-m-pentane			
methylcyclopentane	n.a	n.a	n.a
n-hexane			
cyclohexane			

a mixing ratios in ppbC

b not analyzed

One might speculate that these observations result from the slow release of hydrocarbons trapped in ice fog particles that were collected in the sampling bag. The hydrocarbon data for other days in January appear to suggest that C_2 and C_3 hydrocarbons are associated with stack emission, but C_4 and C_5 hydrocarbons not (see Figure 8). The drastic increase with age of the former class of hydrocarbons would then suggest that the ice fog is formed very close to the point of emission from the stack, and does not grow much after initial formation. The interesting question whether the presence of high levels of hydrocarbons actually promotes ice fog formation can of course not be assessed with these data. If the ice fog is indeed formed very close to the stack (and this seems entirely reasonable) then one would suspect that high levels of SO_2 are dissolved in the fog particles as well. Some fog water was actually collected but only the pH (ca. 4.5) could be estimated with the crude procedures that were followed.

In an earlier theoretical study it was attempted to derive the observed SO_2 oxidation rate and current formation of an O_3 bulge during the 1977 plume studies with typical hydrocarbon levels as observed here (Bottenheim and Strausz, 1981) . It was shown that the observations could only be explained if additional assumptions were made pertaining to levels of aromatic and oxygenated hydrocarbons, for which no analysis was possible during the 1980 studies. However it would be instructive to use the hydrocarbon observations to estimate the concentration of OH radicals in the plumes. A procedure for making such an estimate has been suggested by Calvert (1976) . It is based on the assumption that the change in the ratio of two hydrocarbons with plume age is due to the different reaction rate with OH. In order to use this procedure, data have to be available for two hydrocarbon species with a fairly large difference in reaction rate with OH, while ideally their background levels should be much lower than those observed within the plume. The ratio of two hydrocarbons is used in order to minimize the effect of concurrent plume dilution.

Inspection of the hydrocarbon data set shows that the calculation might be attempted for 21-3,25-3 and 4-7. The formula used to estimate the OH concentration was

$$\frac{\Delta \ln (C_1/C_2)}{\Delta t} = (-k_1 + k_2)\,[OH] \qquad \text{(IV)}$$

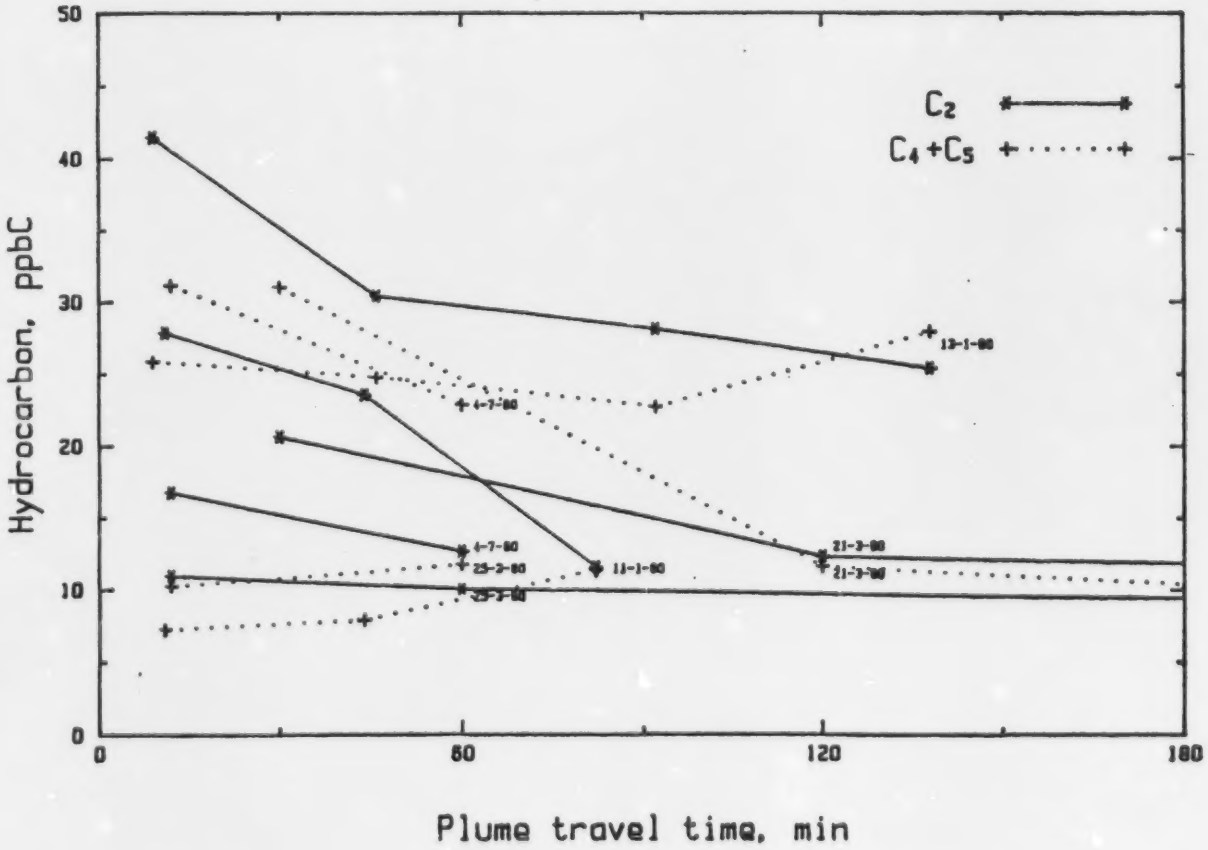


Figure 8. Hydrocarbon content of the Syncrude plume as function of plume travel time.

and the results are presented in Table 7. It is surprising to see that these calculations suggest the same level of OH radical concentration for March and July. OH radical formation to levels of 10^6 molec.cc^{-1} is generally thought to be the result of photochemical reactions. Although all three days considered were sunny days, less total radiation was available in March due to the lower solar elevation (see Appendix, 6.6.3).

The effect of the solar zenith angle on the efficiency of atmospheric photochemical reactions is expected to be especially strong on those reactions that depend on radiation below ca. 3400 Å. The photochemical reactions in the atmosphere that lead to OH radical formation are

$$O_3 + h\nu\ (\lambda < 3200) \rightarrow O\ (^1D) \xrightarrow{H_2O} 2OH \qquad (1)$$

$$CH_2O + h\nu\ (\lambda < 3400) \rightarrow H + HCO \xrightarrow{O_2,\ NO} OH \qquad (2)$$

$$HONO + h\nu\ (\lambda < 3800) \rightarrow OH + NO \qquad (3)$$

Of these reactions, reaction 1 is generally accepted as the route of OH formation in clean air, while reactions 2 and 3 occur in polluted air. From the indicated wavelength limits it can be seen that reaction 1 is expected to be much less effective in March than July, reaction 2 should be also reduced substantially, while reaction 3 will probably be least effected by the wavelength effect. If therefore the OH radical concentrations derived here reflect the atmospheric levels, then it would appear most likely that reaction 3 is the source. In this respect it is interesting to note that the theoretical plume study of Bottenheim and Strausz (1981) suggested that levels of HNO_2 necessary to effect an SO_2 oxidation rate by OH radicals of ca 1% h^{-1} can be rationalized by assumming heterogeneous formation of HNO_2 at the early stages of plume dilution.

The estimated OH concentrations can be used to calculate rates of homogeneous gas phase oxidation of SO_2 in the plume. By using $k_{HO+SO2}=1.6\times10^{-12}$ cc. molec.$^{-1}s^{-1}$ the rates are estimated as 4.0, 1.7 and 2.9%h^{-1} for 21-3, 25-3 and 4-7 respectively. For 21-3 the filterpack data do not show an increase in the SO_4/total-S ratio with plume age. Data for this day are somewhat suspect due to the very low windspeed at that day,

Table 7. Estimated OH Radical concentrations by using hydrocarbon data[a].

Data	HC1/HC2	$-k_1+k_2$ [b]	Time (min)	HC1 (ppbC)	HC2 (ppbC)	[OH] (molec.cc^{-1})
21-3	C_2H_4/C_2H_6	7.6	30	4.3	1.4	2×10^7
			120	13.7	8.7	
	C_3H_6/n-C_4H_{10}	22.	30	2.1	0.4	6×10^6
			120	9.2	3.7	
25-3	C_2H_4/C_2H_6	7.6	12	1.0	0.9	3×10^6
			60	8.5	8.1	
4-7	C_3H_6/n-C_4H_{10}	22.	12	2.5	1.2	5×10^6
			60	8.6	5.6	

a Using equation IV, see text
b Rate constants from Atkinson et al. (1979).

coupled with a probable substantial lateral dilution (see section 3.4). However the estimated rates of SO_2 oxidation from filterpack data and OH radical concentration estimates for 25-3 and 4-7 do agree extremely well (1.5 vs 1.7 for 25-3, and 2.7 vs 2.9 for 4-7 respectively); in fact such a good agreement is probably fortuitous. A similar estimate of the rate of NO_x-nitrate conversion, using $k_{HO+NO2} = 1.1x10^{-11}$cc. molec.$^{-1}s^{-1}$, (Baulch et al., 1982) results in rates of 11.9 and 19.8% h^{-1} for 25-3 and 4-7 respectively. The conversion rates deduced from filter pack data were 5.6 and between 11.1 and 20.6% h^{-1} (section 3.2).

With the data at hand it is not realistic to give much weight to the quantitative results derived here. Nevertheless qualitatively these data do unmistakenly imply that homogeneous gasphase processes play a major role in the formation of sulphate in March as well as July.

3.4 DISPERSION

The data obtained in these field studies were not intended to study plume dispersion, and for a proper analysis several ancillary pieces of information would be required. Nevertheless it is instructive to determine the consistency of the data set in this respect. Hence for each sampling day for which a determination of SO_2-oxidation rates was attempted in earlier sections of this report, a few arbitrarily chosen plume-transects were analyzed. The σ_D values as well as the maxima of the SO_2 mixing ratio were obtained using a procedure developed by Davison et al. (1977) (Thanks are due to Dr. Davison for supplying the computer code that was used here). For these calculations the plume transsect data from the in situ SO_2 monitor were used. The results are presented in Table 8. As an example of the derived Gaussian profiles, Figures 9 and 10 show successive plots for data of 13-1 and 25-3. As should be expected the variance in these numbers and figures is rather large, and to obtain more reliable estimates the full data set should be analysed. The purpose here was only to determine the order of magnitude of plume dispersion.

It is remarkable to note the very slight plume dispersion during January. Apparently the very stable atmospheric conditions during that time prevented not only vertical mixing but kept the plume also very compact in the

Table 8. Plume Dispersion Calculation Data.

Date	Distance (mi)	Time (min)	σ_D	$C_{max, exp}$ (ppb)	$C_{max, est}$ (ppb)
11-1	2	14.03	290	427	462
		14.14	198	317	285
	8	14.51	245	755	754
		14.53	395	663	692
		15.01	282	616	524
	15	15.50	1231	87	63
		15.54	1484	120	80
13-1	2	11.17	105	696	949
		11.22	164	551	566
	10	11.51	306	260	285
		11.53	491	310	282
	20	12.32	513	70	75
		12.44	343	116	100
	30	15.55[b]	702	6.7	6.2
21-3	2	12.39	819	364	345
		13.00	805	399	333
		13.02	659	385	369
	8	14.28	1167	32	32
		14.31	1530	33	28
25-3	2	10.23	578	440	400
		10.27	551	446	382
		10.51	308	480	439
		10.52	256	452	383
	6	13.16	484	266	189
		13.27	284	441	412
		13.47	623	311	267
	25	14.30	1029	63	58
		14.33	1674	62	55
		14.36	1347	64	59
		14.40	1315	61	53
4-7	1	10.41	388	875	727
		10.59	292	665	524
		11.02	180	830	890
	5	11.23	292	385	360
		11.34	210	354	270
		12.06	241	355	326

[a] MST in January and March, MDT in July
[b] Based on NO_x; no SO_2 trace available

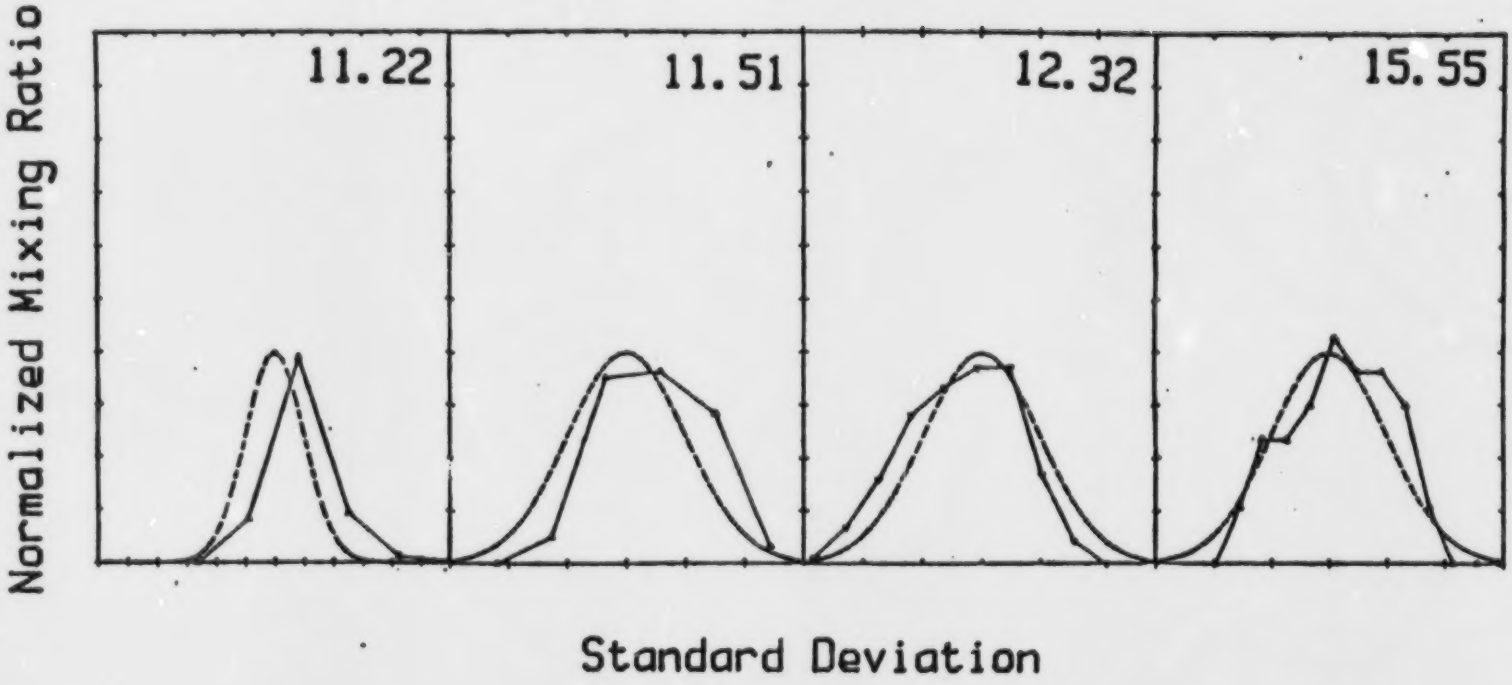


Figure 9. Comparison of unormalized plume transect data for SO_2 with true Gaussian profiles for arbitrarily chosen transects of successive plume samplings on 13-1-80. The profile for 15:55 refers to NO_x rather than SO_2 (no SO_2 chart recorder trace available).

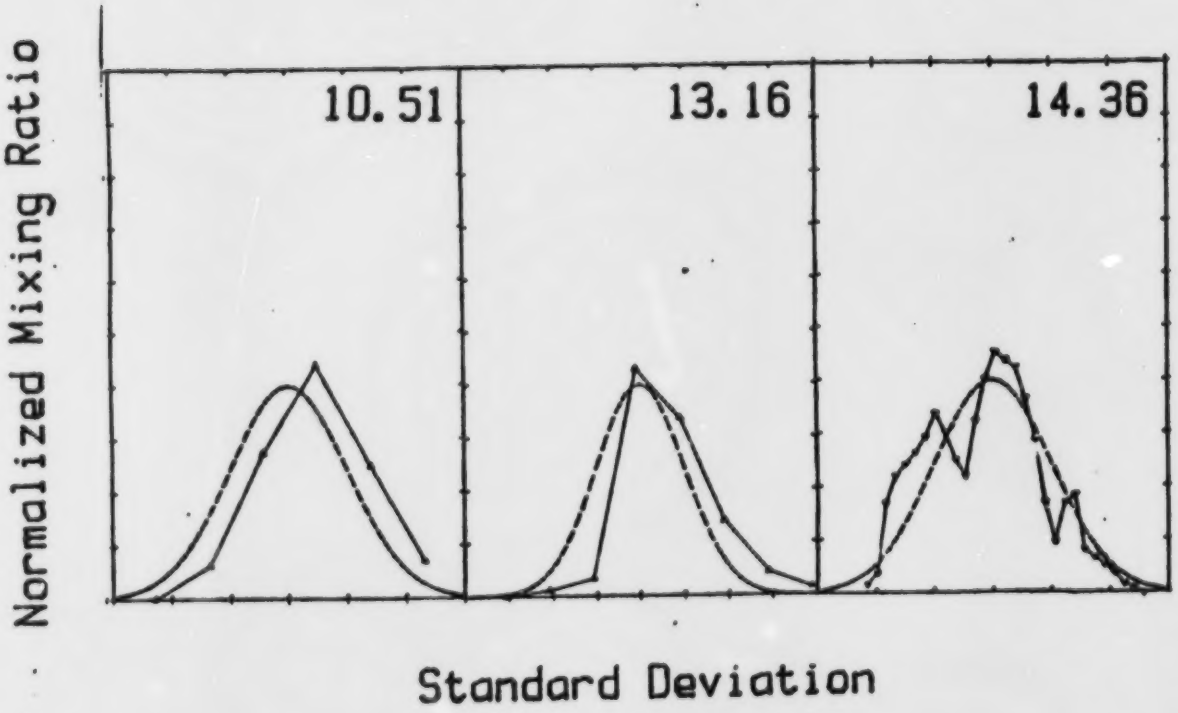


Figure 10. Comparison of normalized plume transect data for SO_2 with true Gaussian profiles for arbitrarily chosen transects of successive plume samplings on 25-3-80.

horizontal directions. The data for March show considerably more plume spreading, These data are rather similar to those observed during the earlier field studies. Finally, the data for July 4 are suspect due to the problems with the SO_2 analyser (see section 3.1). Unfortunately, as mentioned earlier, no useful NO_x data are available on the data tape to make an independent check of these results.

Another analysis that can be made with these data is determination of the plume dispersion parameters α' and β as defined in Bottenheim and Strausz (1981, page 56). There it is derived that the SO_2 concentration at the plume centre should have the functional form

$$c_m(t) = \alpha' t^{-\beta} \qquad (V)$$

α' and β values were derived from the data of Table 8 using the averaged observed maxima. These data are shown in Table 9. β values can also, independently, be derived from the hydrocarbon data. For this purpose, the assumption is made that hydrocarbons originating from the plants are within the plume at the first sampling location. A detailed analysis of the hydrocarbon dataset shows that this assumption is probably correct for the C_2 and C_3 hydrocarbons, but, surprisingly enough, not necessarily for the C_4 and C_5 species, particularly in January (see Figure 8). Since for March the C_3 data are unavailable (see Appendix 6.4), for January and March the β values were determined on the basis of C_2 data only. For 4-7 on the other hand the total C_2 - C_5 hydrocarbon mix was used, since no discrepancies for C_4 and C_5 were apparent.

The β values were determined from the formula

$$\bar{c}(t) = c_o t^{-\beta} + c_B(1-t^{-\beta}) \qquad (VI)$$

where $\bar{c}(t)$ is the average concentration at plume age t, c_o the extrapolated concentration at the chimney, and c_B the concentration in the background air. For c_B the concentration at the longest distance from the chimney was used if no background measurement was available. Equation VI is equivalent to equation V since for SO_2 $c_B \sim 0$ and for a Gaussion distribution the average concentration $\bar{c}$

Table 9. Dispersion factors α' and β[a]

	SO_2		HC
Date	α'	β	β
11-1	1.7×10^3	.54	.28
13-1	4.5×10^3	.78	.69
21-3	7.2×10^4	1.38	1.36
25-3	3.3×10^3	.69	.55
4-7	5.2×10^3	.72	.83

a See text for definition of α' and β, and data used to derive these values.

$$\bar{c} = f \cdot c_m \qquad \text{(VII)}$$

where $f \sim 0.4$.

The β values obtained from these calculations are also presented in Table 9. Only for 11-1 the comparison between SO_2 and C_2 hydrocarbon data shows a large discrepancy. The reason for this fact is not clear. It should be mentioned that on this particular day several problems with icing of sampling lines were encountered. One would suspect that such problems would have a larger influence on the in-situ SO_2 detector than the hydrocarbon sampling. On the other hand the β value from the C_2 -hydrocarbon data seems to be abnormally low. For the other days the data are within 20% of each other. In view of the crude procedures used here and the very limited set of data, this is construed as an indication that the SO_2 data are consistent with the hydrocarbon data.

4. SUMMARY AND RECOMMENDATIONS

This study was undertaken to obtain information on the atmospheric chemistry in the Alberta Tar sands area. As with many field studies, several problems were experienced that limit the extent to which definite statements pertaining to the transformation chemistry of SO_2 and NO_2 can be made. Nevertheless several interesting conclusions could be reached.

The results from this study reconfirm the importance of homogeneous gas phase reactions in the area. It appears that oxidation of SO_2 by OH radicals is a major process leading to sulphate formation. Surprisingly this does not only apply for summer conditions. On one sunny day of observed SO_2 oxidation in March the independently derived OH radical concentration was such that all oxidation could be due to the OH + SO_2 reaction. On the other hand, increase in the SO_4/total sulphur ratio was observed in January as well (no OH radical concentrations could be estimated in this case), and it was argued that these observations suggest that aqueous phase oxidation via metal-ion catalysis does occur. In this respect it was noted that transformation from SO_2 to sulphate, when observed, appeared to be limited always to the first hour of plume age, as one would expect for metal-ion catalyzed reactions.

Very few useful data were available study the NO_x → nitrate transformation chemistry. Some tentative rates were estimated that indicated that such transformation occurs, most likely via the OH+NO_2 reaction, i.e. again in the gas phase.

Ozone data were obtained which confirmed the theoretically estimated annual variation in the area. In January and March, ozone within the plume always showed a decrease from the ambient levels. In July on the other hand excess ozone was observed when the plume had aged for more than an hour.

Hydrocarbons that were observed in the plume appeared to originate directly from the stack, possibly mixed to some extend with flare gas exhaust. The ambient air in the area had very low hydrocarbon levels. Evaporative emission from the open pit mine seemed to contribute rather little. The total amount of hydrocarbons observed raises the question as to

how to explain the excess ozone in the summer plume. The reactivity of the hydrocarbon mix would not seem sufficient to create ozone bulges. It is entirely possible, however, that aromatic hydrocarbons as well as oxygenated species (aldehydes, ketones) for which no analysis could be performed in this study, constitute the missing link. A sample collected in a winter ice fog seemed to suggest that large amount of emitted hydrocarbons can be incorporated in ice fog particles. The importance of this observation is presently not clear.

From the hydrocarbon data it was possible to estimate the OH radical concentration in the plume. Since very little difference between the March and July cases was observed, it was argued that the most likely source of OH radicals is the photolysis of nitrous acid. Finally a limited attempt was made to derive dispersion parameters from the data. It appeared that during the very cold January study the plume did not disperse very much at all. Since the plume was never observed to penetrate the surface inversion layer during that time, it is likely that under those conditions the pollutants will travel over very long distances, if not subjected to precipitation scavenging. A further analysis comparing dispersion data from SO_2 observations with those of hydrocarbons showed a reassuringly high correlation.

From the summary of the results of this study the following recommendations for further study can be made.

1. Winter time study. The present study found indications of SO_2 oxidation in the winter, in contrast with earlier studies in the area. Heterogeneous oxidation was suggested as the possible mechanism; however, no pertinent data to substantiate this suggestion were obtained. Furthermore, little plume dispersion seemed to occur suggesting potentially very long range transport. Also at least on one day substantial amounts of ice fog were encountered, which showed some curious effects as far as hydrocarbons were concerned. All these facts suggest that a more concerted effort to study the winter time plume is in order. In such a study one would like to focus in particular on the aqueous and aerosol chemistry.

2. NO_x → nitrate transformation. The interpretation of the data obtained does suggest that such transformation takes place. However contrary to the conditions in Eastern Canada causing acidifying precipitation, it is clear that in the Tar sands plumes nitrate will in all seasons be a minor

constituent compared with sulphate. Nevertheless future studies should more clearly determine the nitrogen chemistry. With progress in instrument development since the time of these studies it should now be possible to better evaluate sulphate/nitrate ratios.

3. Hydrocarbons. Although it was possible to estimate a few OH radical concentrations from the data, a major missing factor pertains to the absence of information on aromatic and oxygenated hydrocarbons. In particular, the data obtained were not sufficient to explain excess ozone formation in the summertime plume. Hence, any future study should continue to analyze for hydrocarbons and extend this to at least the more common aromatics.

4. Meteorological data. For this study it was decided to rely on the observations at the Fort McMurray airport as far as the current weather conditions were concerned. For the upper wind data this is probably acceptable. The terrain features in the area can however have a strong influence on the lower boundary layer, and hence considerable uncertainties arise with respect to wind and temperature profiles that are relatively easily obtained close to the stack. The problems with the data obtained on 7-7 and 8-7 might have been prevented if locally minisonde releases had taken place. It seems therefore important to recommend that future plume chemistry studies devote more time and manpower to the collection of meteorological data.

5. QC and QA. A major setback in the data analysis was the realization after the fact that most of the information on the data tapes from the summer study was illegible. This is but one example of problems that could have been prevented,had a quality control and assurance program been in place during this study. It should be mentioned here that the lack of such a program during the study is a reflection of the very limited manpower that was available. Nevertheless, any future study should place priority on a QC and QA program. This might result in a decreasing scope of the data to be collected, if only limited manpower is available.

5. LITERATURE CITED

Atkinson, R., K.R. Darnall, A.C. Lloyd, A.M. Winer, and J.N. Pitts, Jr. 1979. Kinetics and mechanisms of the reaction of the hydroxyl radical with organic compounds in the gas phase. Adv. Photochem. 11: 375.

Baulch, D.L., R.A. Cox, P.J. Crutzen, R.F. Hampson, Jr., J.A. Kerr, J. Troe, and R.T. Watson 1982. Evaluated Kinetic and Photochemical Data for Atmospheric Chemistry: Supplement 1. CODATA Task Group on Chemical Kinetics. J. Phys. Chem. Reference Data 11: 327.

Barrie, L.A. 1980. The fate of particulate emissions from an isolated power plant in the oil sands area of Western Canada. Ann. N.Y. Acad. Sci. 338:434.

Bottenheim, J.W., and O.P. Strausz 1979. The effect of a polluting source on the air quality downwind of pristine northern areas. Atmos. Environ. 13: 1085.

Bottenheim, J.W., and O.P. Strausz 1980. Gas-phase chemistry of clean air at 55° N. Latitude. Environ. Sci. Technol. 14: 709.

Bottenheim, J.W., and O.P. Strausz 1981. Development of a chemically reactive plume model for application in the AOSERP study area. AOSERP Report No. 117.

Calvert, J.G. 1976. Hydrocarbon involvement in photochemical smog formation in Los Angeles atmosphere. Environ. Sci. Technol. 10: 256.

Chameides, W.L., and R.J. Cicerone 1978. Effects of nonmethane hydrocarbons in the Atmosphere. J. Geophys. Res. 83C: 947.

Cronn, D., and E. Robinson 1979. Tropospheric and lower stratospheric vertical profiles of ethane and acetylene. Geophys. Res. Lett. 6: 641.

Davison, D.S., C.J. Fortems, and K.L. Grandia 1977. Plume dispersion measurements from an oil sands extraction plant, March 1976. AOSERP Report 13.

Denison, P.J., R.A. McMahon, and J.R. Kramer 1979. Literature review on pollution deposition processes. AOSERP Report 50.

Fanaki, F. (compiler) 1979a. Air system winter field study in the AOSERP study area, February 1977. AOSERP No. 24.

Fanaki, F. (compiler) 1979b. Air system summer field study in the AOSERP study area, June 1977. AOSERP Report No. 68.

Forest, J., and L. Newman 1977. Further studies on the oxidation of sulphur dioxide in coal-fired power plant plumes. Atmos. Environ. 11: 465.

Freiberg, J. 1976. The iron-catalyzed oxidation of SO_2 to acid sulphate mist in dispersing plumes. Atmos. Environ. 10: 121.

Newman, L., J. Forrest, and B. Manowitz 1975a. The application of an isotopic ratio technique to a study of the atmospheric oxidation of sulfur dioxide in the plume from an oil-fired power plant. Atmos. Environ. 9: 959.

Newman, L., J. Forest, and B. Manowitz 1975b. The application of an isotopic ratio technique to a study of the atmospheric oxidation of sulfur dioxide in the plume from a coal-fired power plant. Atmos. Environ. 9: 969.

Sexton, K., and M. Westberg 1979. Ambient air measurement of petroleum refinery emissions. J. Air Poll. Contr. Assoc. 29: 1149.

Shelfentook, W. 1978. An inventory system for atmospheric emission in the AOSERP study area. AOSERP Report No. 29.

Stevens, R.K. (editor) 1979. Current methods to measure atmospheric nitric acid and nitrate artifacts. U.S. EPA Report No. EPA-600/2-79-051.

6. APPENDICES

6.1 AIRBORNE PLATFORM DESCRIPTION AND FLIGHT PROCEDURES[1]

6.1.1 Aircraft Operations

INTERA's Twin Aztec aircraft was used for the two field programs in January and March 1980. Under a separate contract with the Alberta Department of Environment, this aircraft had been configured for airborne particulate and gaseous sampling for the Calgary airshed, and was available, with limited mobilization, for this sampling program.

The equipment used for this study is listed in Table 10, along with the manufacturer's response accuracy. The primary data acquisition system was the Monitor Labs 9400-Cipher tape transport. This system is a time-synchronized, high-speed sequential analog to digital signal converter, complete with separate controls for signal filtering and amplification for each input analog channel. After the data are digitized, they are formatted for recording onto 1/2" computer compatible tape via the Cipher tape transport.

In order to have an onboard real-time display of the trace gases, an MFE 2-channel recorder was installed to display SO_2 and NO_x. The primary purpose of this real-time display was for plume encounter at downwind distances where the plume might not be visible. As part of the technician's laboratory support equipment, a second MFE 2-channel recorder was taken as a spare.

Prior to installation in the aircraft the equipment was calibrated and bench-checked, and appeared to function properly. However, during the first mission in January the primary data acquisition system failed to operate normally in the extreme cold conditions. It was decided to install the back-up MFE recorder to record NO and O_3 data, as the serviceability of the primary system looked doubtful. After several attempts to repair it, the Monitor Labs

---

[1] This section was summarized from reports by INTERA Environmental Consultants Ltd. (Final Report on the Airborne Plume Measurements in the Alberta Oil Sandw Region, December 1980; Final Report on the July Plume Measurements in the Alberta Oil Sands Region, December 1980).

Table 10. Aircraft equipment during January and March 1980.

1.	Temperature	Rosemont 102u2u	-50°C to 50°C	±0.1°C
2.	Dew Point	Metrodata M-8 Vis strip	3-98% RH	±4%
3.	Atmospheric Pressure	Metrodata M-8 Pressure	0-30,000' MSL	±75'
4.	SO_2	Mulloy Model 285	0.5ppb - 1000ppb	±0.5ppb
5.	$NO-NO_x$	Monitor Labs Model 8440	2ppb - 5ppm	±75'
6.	O_3	Dasibi Model 1003	3ppb - 20ppm	±1%
7.	Impact Filter	-	-	-
8.	Hi-Vol Filter	-	-	-
9.	Air Bag Sampler	-	-	-
10.	Data Acquisition	Monitor Labs 9400 Cipher Tape Transport		
11.	Data Acquisition	MFE Chart Recorder		

system failed. That effort was terminated, and the paper trace recordings became the primary data recovery system.

When the aircraft returned to Calgary following the January field program the equipment was again bench-checked, and the Monitor Labs Cipher system was repaired. Once the entire system was checked out, it was reinstalled in the Aztec for the second field program. However, once again the primary data acquisition system did not function properly in the field, and the backup system was needed.

There were two main consequences of this failure of the magnetic tape recording system. For one thing, there was no longer a time history of the temperature, moisture, and pressure sensors. This was compensated by the technician recording notes of the flight altitude and outside air temperature during soundings and transects. The second consequence of above problem was the requirement to have the paper trace data digitized for subsequent analysis.

INTERA's Cessna 411 aircraft was used for the June/July field program. Figure 11 shows the aircraft with the sampling probes for this study. The equipment used was similar to that used for the winter studies, with the addition of a Ball model 210 Airspeed monitor (see Table 11). Figure 12 shows the interior installation of the sensor units and the data acquisition system. Figure 13 is a plan view schematic of the equipment rack layout. Note that the equipment was laid out for ease of access by the technician, including the filter and air-bag samplers.

During the summer studies problems arose initially with the Meloy-285 SO_2 monitor that required considerable ground servicing, and the study was temporarily halted between 28 June and 03 July to get the instrument functioning properly. More seriously, it turned out after completion of the field study that the data acquisition system had once again failed. As a consequence most information on the data tapes could not be deciphered, and once again data from back-up chart recorders have become essential for data evaluation. It should be pointed out that initially during the study the data tapes had been tested to determine whether they contained data (numbers), but <u>not</u> whether these data were

Figure 11. Cessna 411 showing location of sampling probes.

Table 11. Aircraft equipment during June/July 1980.

1.	Temperature	Rosemont i02u2u	-50°C to 50°C	±0.5°C
2.	Dew Point	E.G. & G. model 137	-50°C to 50°C	±0.5°C
3.	Atmospheric Pressure	Ball model Ex 410	0-30,000' MSL	±75'
4.	Airspeed	Ball model Ex 210	0-200 KIAS	±2 KTS
5.	SO_2	Meloy Labs model SA285	0.5 ppb-1000 ppb	±0.5 ppb
6.	$NO-NO_x$	Monitor Labs model 8440 E	2 ppb- 5 ppm	±1%
7.	O_3	Monitor Labs 8410 A	3 ppb-20 ppm	±1%
8.	Impact Filter	-	-	-
9.	Hi-Vol Filter	-	-	-
10.	Air Bag Sampler	-	-	-
11.	Data Acquisition	Monitor Labs 9400 Cipher Tape Transport	-	-
12.	Data Acquisition	MFE Chart Recorder	-	-

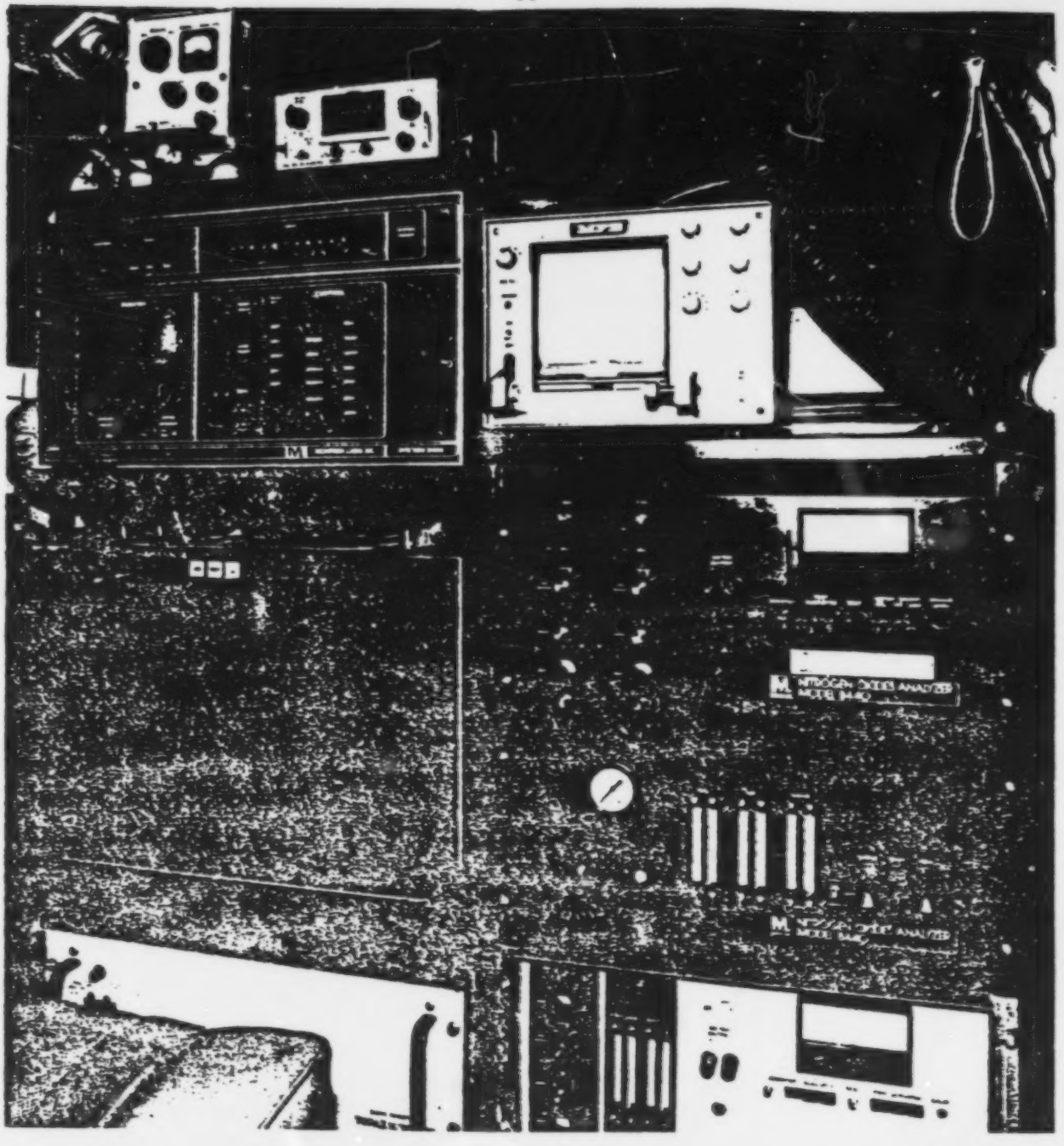
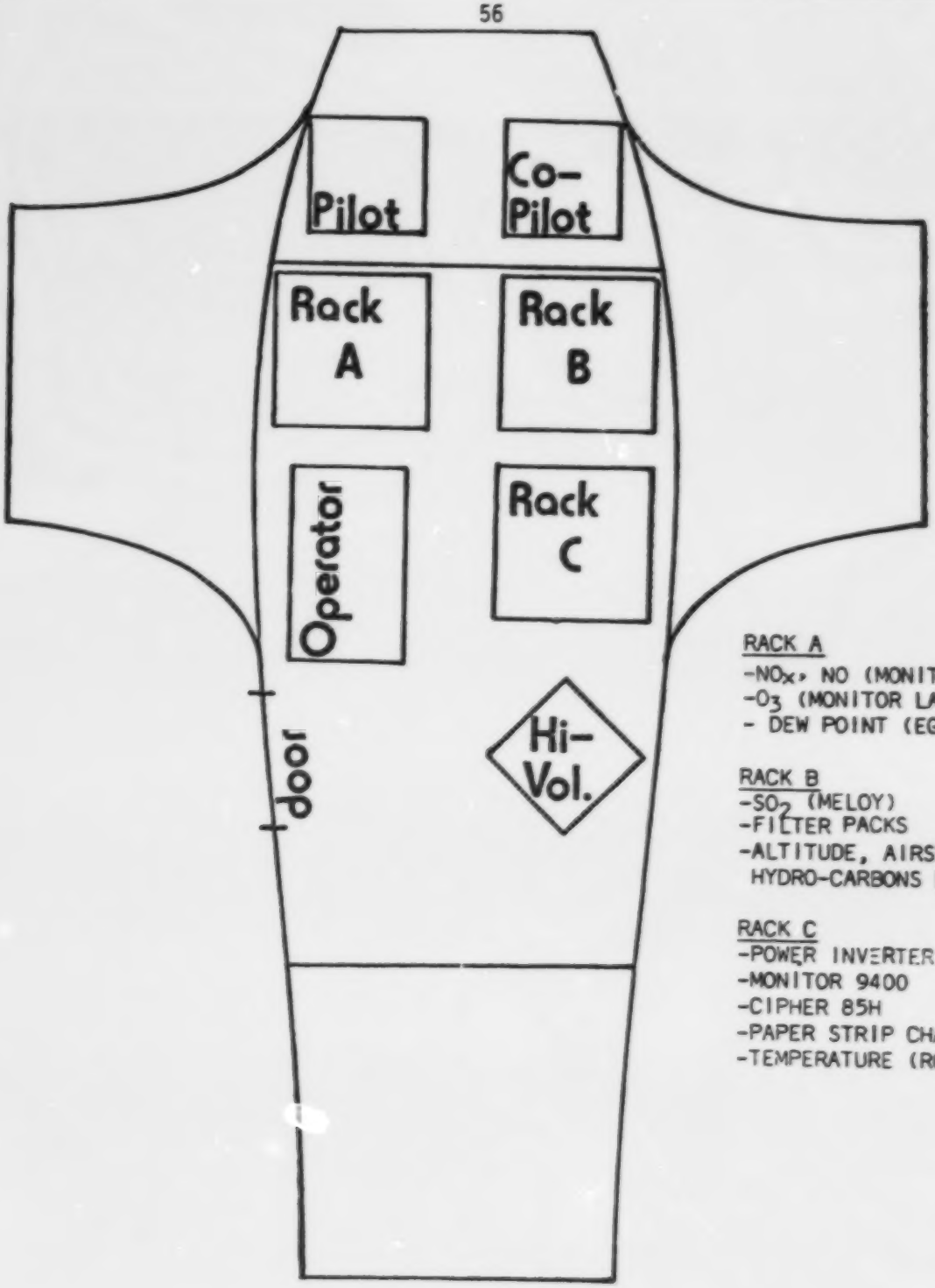


Figure 12. Typical sensor units and data acquisition system.



RACK A
- NO_x, NO (MONITOR LABS)
- O_3 (MONITOR LABS)
- DEW POINT (EG & G)

RACK B
- SO_2 (MELOY)
- FILTER PACKS
- ALTITUDE, AIRSPEED (BALL)
  HYDRO-CARBONS BAG

RACK C
- POWER INVERTER (TOPAZ)
- MONITOR 9400
- CIPHER 85H
- PAPER STRIP CHART (MFE)
- TEMPERATURE (ROSEMOUNT)

FIG. 13.

Inside Schematic of INTERA'S
Cessna 411 configured for AOSERP
plume chemistry study.

bearing any relationship with the actually monitored parameters (monitor-values).

6.1.2 Flight Profiles

The purpose of this data gathering study was to collect filter and air bag samples of plume concentrate, as well as background samples. In order to ensure that the filter samples were adequately exposed for analysis, the flight profiles consisted primarily of multiple crosswind transects through the plume centerline concentration, rather than vertically stacked crosswind transects. The aircraft was positioned such that several sets of downwind trasects were conducted through the plume, as well as one upwind background set of runs.

Once the series of transects were started the filter pack was continuously exposed. The air bag sample, on the other hand, was exposed only when the aircraft was in the plume. The real-time displays from the MFE recorder assisted in the detection of the program encounter. Throughout the flights the aircrew maintained two-way communications with the project leader at the Mildred Lake laboratory for updates on the flight profiles, and to relay our observations and measurements. This provided guidance regarding exposure of the plume samples and the desired downwind distances.

Typically during a flight the aircraft conducted a temperature sounding up to approximately 10,000' MSL. It was discovered that such a sounding should be conducted prior to collecting air-bag samples, as the decrease in pressure would result in rupturing the bag.

During the January and March field studies, the aircraft was based at the Fort McMurray airport to be able to park the plane in a hanger; in June/July the flights operated from the Mildred Lake airstrip. In order to allow for proper storage of exposed filters and rapid analysis of bag samples, the aircraft landed in January and March at the Mildred Lake airstrip after a mission to turn over the filter and bag samples, whenever possible.

6.1.3 Meteorological Data

The flight crew had a weather briefing before each mission for a general synoptic outlook and to assist in the mission planning.

Furthermore, once airborne, the weather observations and forecasts were updated via direct contact with the flight service station.

After each mission the surface and upper-air observations from the Fort McMurray airport were collected as part of the data summary for this report. The hourly observations for the periods of the aircraft operations are listed in Appendix 6.2. Also, the upper air data are plotted on a hodograph form, accompanied by the aircraft temperature sounding. These help to describe the airmass into which the plumes were being emitted.

Unfortunately, due to the failure of the primary recording system, there is no complete time history of the temperature and dew point temperature. However the technician's notes of the temperature at sampling altitude and during the soundings does present some meteorological records from the flights.

6.1.4 System Calibration Data

Table 12 presents the equipment calibration schedule for the winter field programs. Note that the three gas analyzers were calibrated prior to each trip to Fort McMurray.

The two calibrations of the Meloy 285 are presented in Figure 14 and 15, respectively. Both curves are linear, although the slopes are significantly different, suggesting a drift in the response characteristics.

The calibrations conducted on the NO_x and O_3 monitors were according to the Alberta DOE lab standards, and the units were adjusted to achieve predetermined response specifications.

Calibrations on the other equipment in Table 12 were conducted at INTERA's lab facility; however, due to the failure of the primary data logging facility, the results of these calibrations will not be repeated here.

The aircraft system for the summer study was bench-checked prior to installation to insure its operation. In addition, the various sensors were calibrated in-flight, and were routinely checked during the

Table 12. Instrument calibration schedule, winter studies.

Instrument	Date of Calibration	Done By
Meloy Labs, SA285	1980 January 07	Western Research
Meloy Labs, SA285	1980 March 13	Western Research
Monitor Labs, 8440E	1980 January 03	Alberta DOE
Monitor Labs, 8440E	1980 March 12	Alberta DOE
Monitor Labs, 8410A	1980 January 03	Alberta DOE
Monitor Labs, 8410A	1980 March 12	Alberta DOE
Rosemount Temperature	1979 October 23	INTERA
Rosemount Temperature	1980 April 03	INTERA
Ball Airspeed	1979 October 23	INTERA
Ball Altitude	1979 October 28	INTERA
Metrodata Temperature	1979 October 23	INTERA
Metrodata Temperature	1980 March 11	INTERA
Metrodata Humidity	1979 October 23	INTERA
Metrodata Humidity	1980 March 11	INTERA
High-Vol Flow Rate	1980 March 17	INTERA

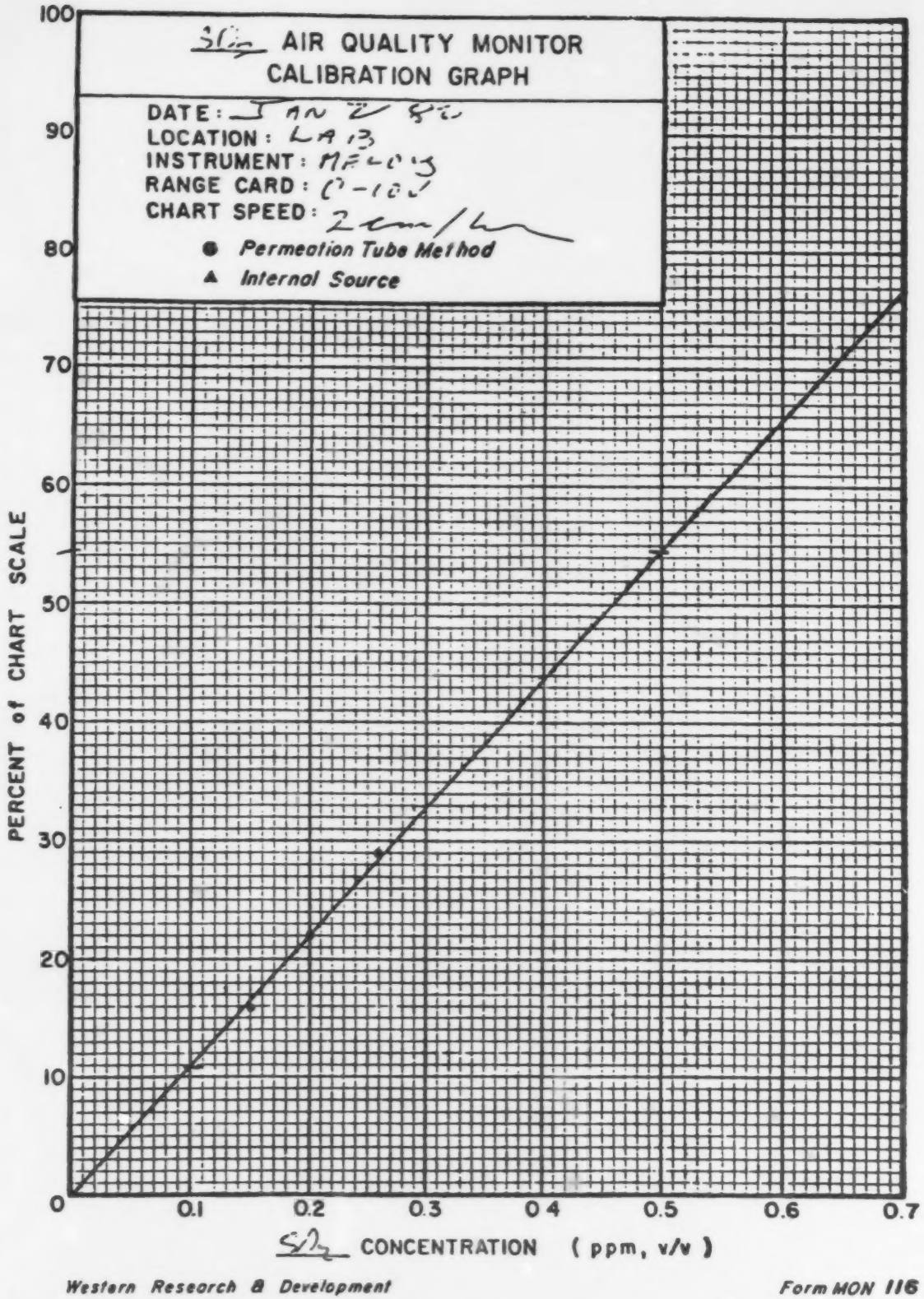


Figure 14. Calibration curve for Meloy 285.

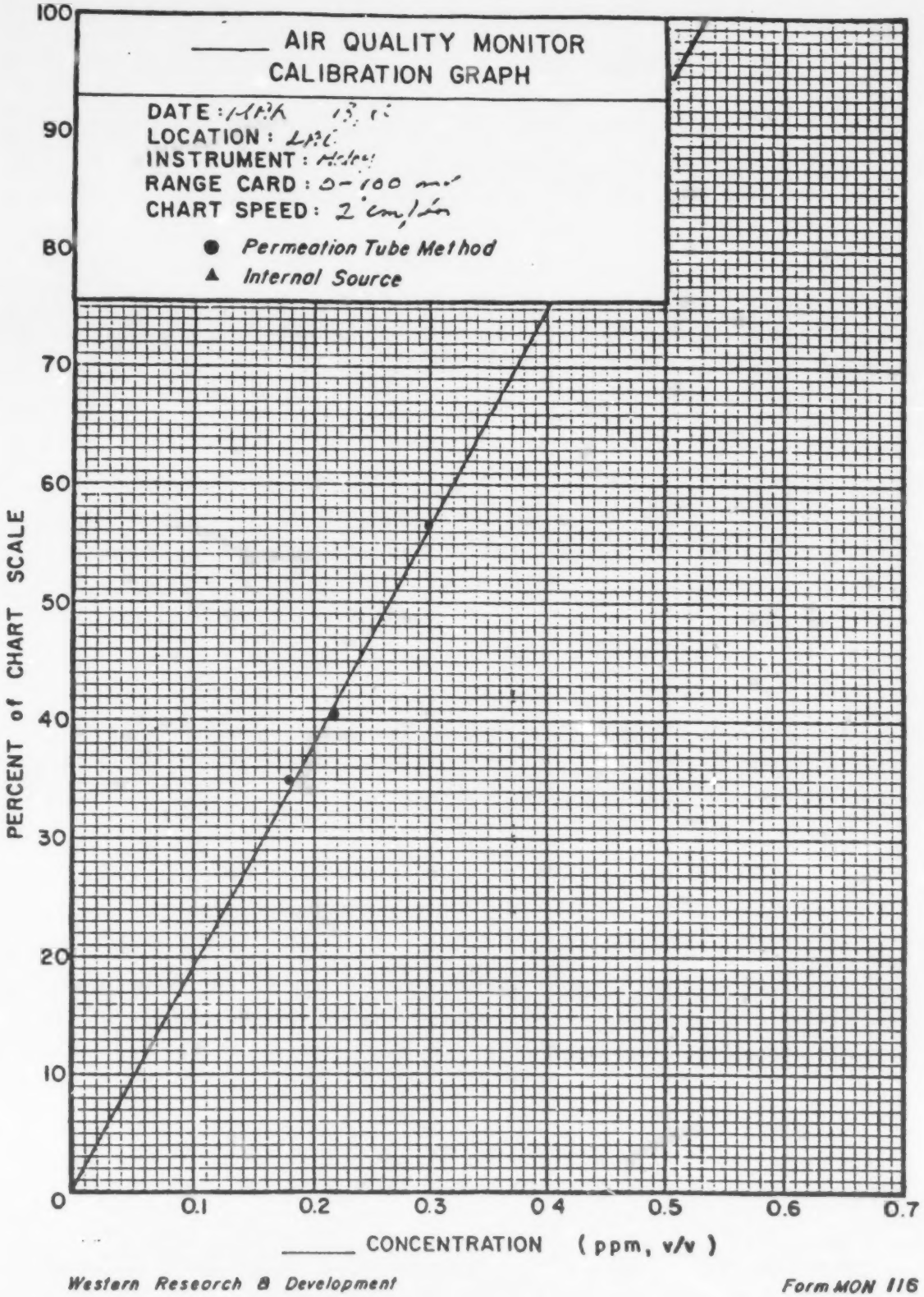


Figure 15. Calibration curve for Meloy 285.

field program. Table 13 lists the channel allocation for the data logging system, along with the sensor range and voltage output.

Note that the four gas analyzers, NO_x, NO, O_3, and SO_2, have "variable range" indicated in the table. The sensor operator selected different ranges depending on the concentrations encountered in flight. These changes are indicated in his flight notes, and presented in the case studies in Appendix 6.2. The DAS output voltage remained 0 to +10 vdc for the selected range.

The calibration data for INTERA's sensors were plotted up to produce calibration functions. Linear equations were derived to fit the data points, for ease in the analyses. Three sensors appeared to follow the linear fit. The fourth, airspeed, did not over the entire range. However, a linear fit was derived for the range 110-130 KIAS, which was the typical aircraft operating speed. The calibration curves are presented in Figures 16 to 20, along with the linear best fit equation.

The gas analyzers and flow rate sensor were delivered to INTERA just prior to the field program. Calibrations on these items were accomplished by Alberta Environment prior to or following the field program, and results of these calibrations are available from Alberta Environment.

6.2 DESCRIPTIVE SUMMARY OF CASE STUDIES[1]

This appendix presents the case summaries from the field programs conducted in the AOSERP region. The cases will be presented in chronological order, and will be followed by figures and tables of the flight operation and the meteorological data. Table 14 and 15 list the flight operations conducted for this study.

The primary objective of the study was to collect filter and airbag samples for either of the two source stacks in the AOSERP region. Case summaries list the filters and air samples collected on the various

---

[1]This section was summarized from reports by INTERA Environmental Consultants Ltd. (Final Report on the Airborne Plume Measurements in the Alberta Oil Sands Region, December 1980; Final Report on the July Plume Measurements in the Alberta Oil Sands Region, December 1980).

Table 13. DAS channel allocation.

Channel	Sensor	Sensor Range	Voltage Output (vdc)
0	N/A	N/A	0
1	Temperature	-50°C to 50°C	0 to +5.0
2	Dew Point	-50°C to 50°C	0 to +5.0
3	Airspeed	0 to 200 KIAS	0 to -2.0
4	Altitude	0 to 20,000 FT. MSL	0 to -5.0
5	NO_x	Variable range	0 to +10.0
6	NO	Variable range	0 to +10.0
7	O_3	Varible range	0 to +10.0
8	SO_2	Variable range	0 to +10.0
9	Differential Pressure	N/A	0 to +10.0
10	Differential Pressure	N/A	0 to +10.0
11	N/A	N/A	N/A
12	Filter Pack Flow Rate	0 to 25 l min^{-1}	0 to +2.5

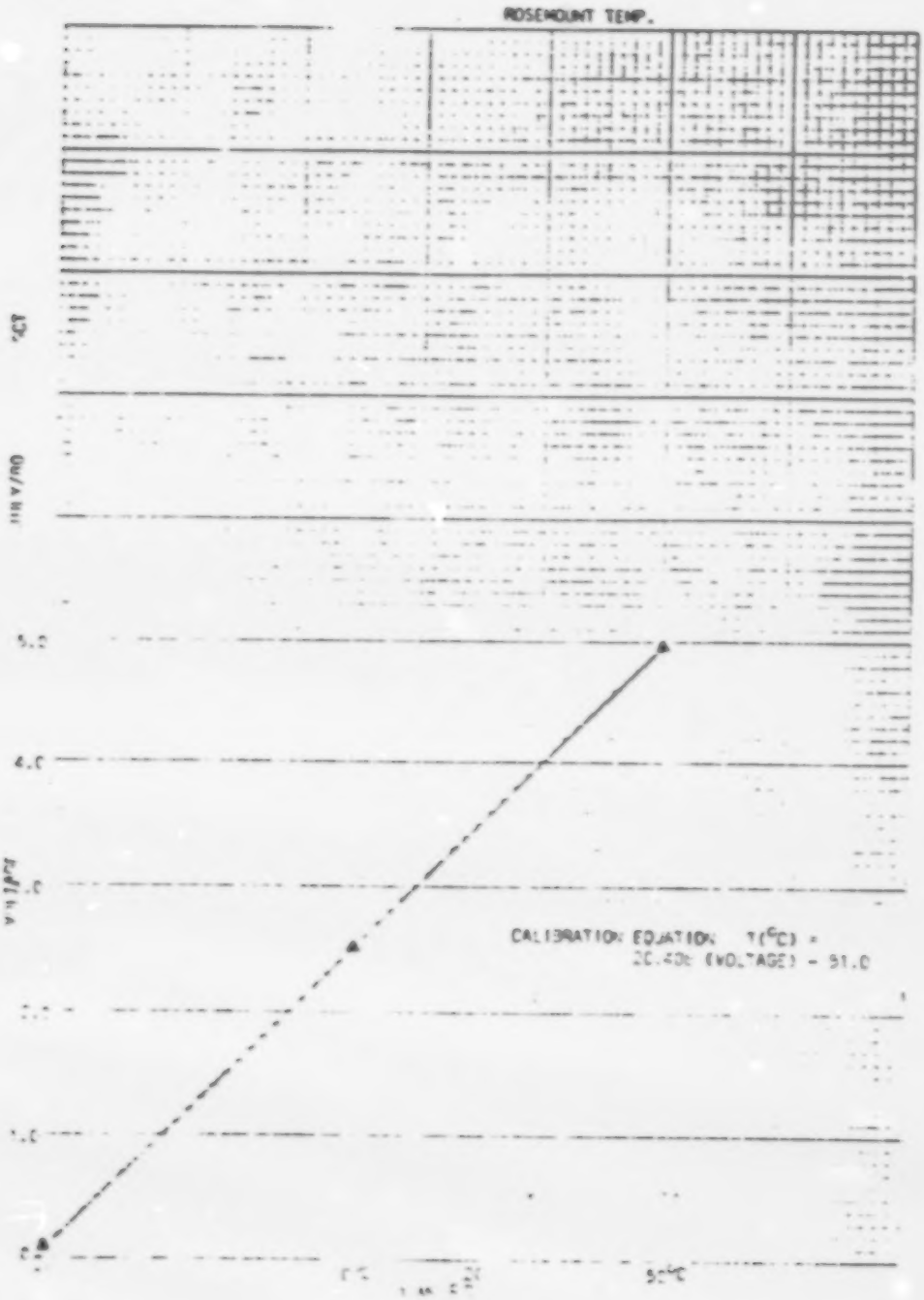


Figure 16. Calibration curve for INTERA's sensors.

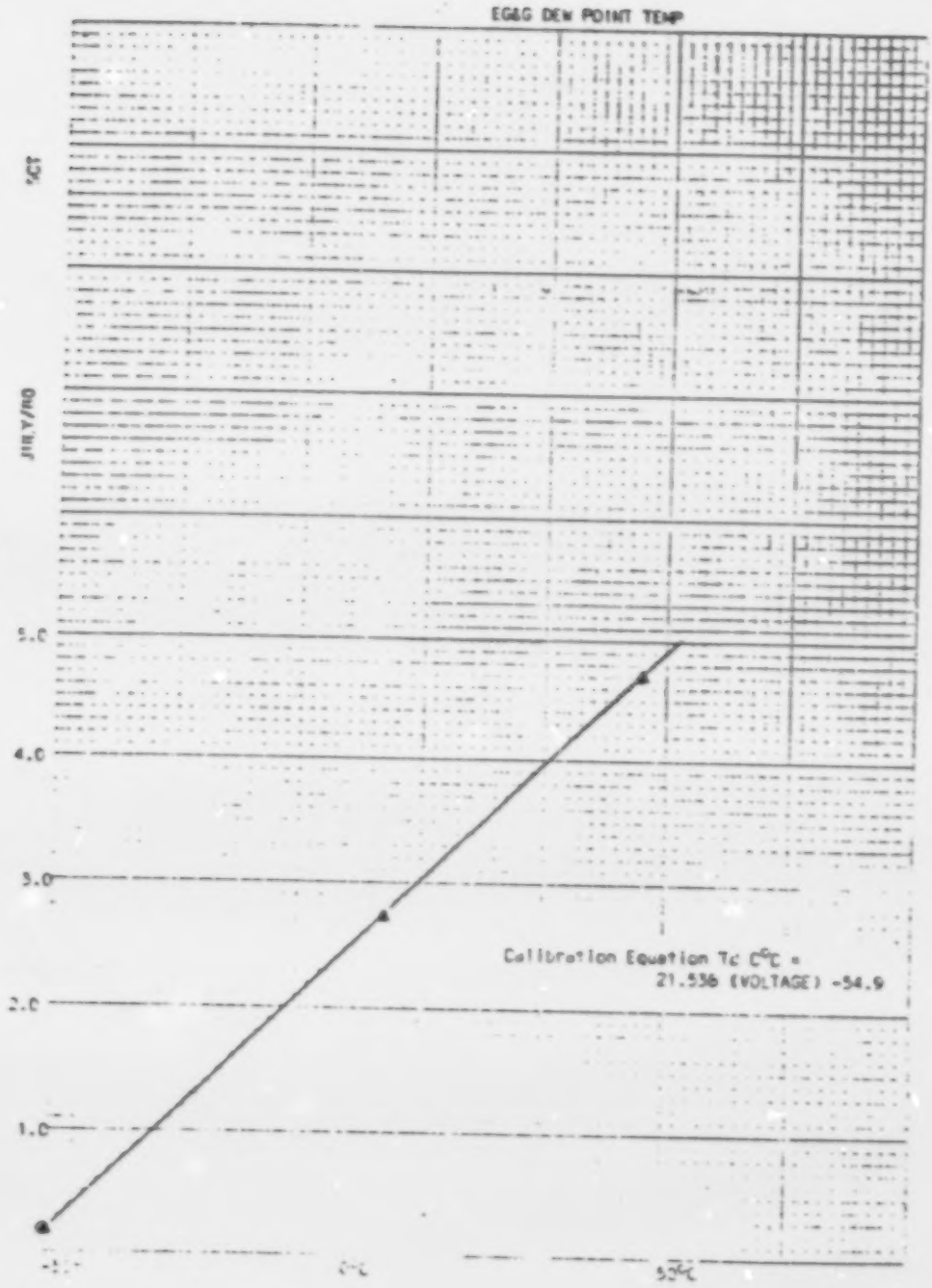


Figure 17. Calibration curve for INTERA's sensors.

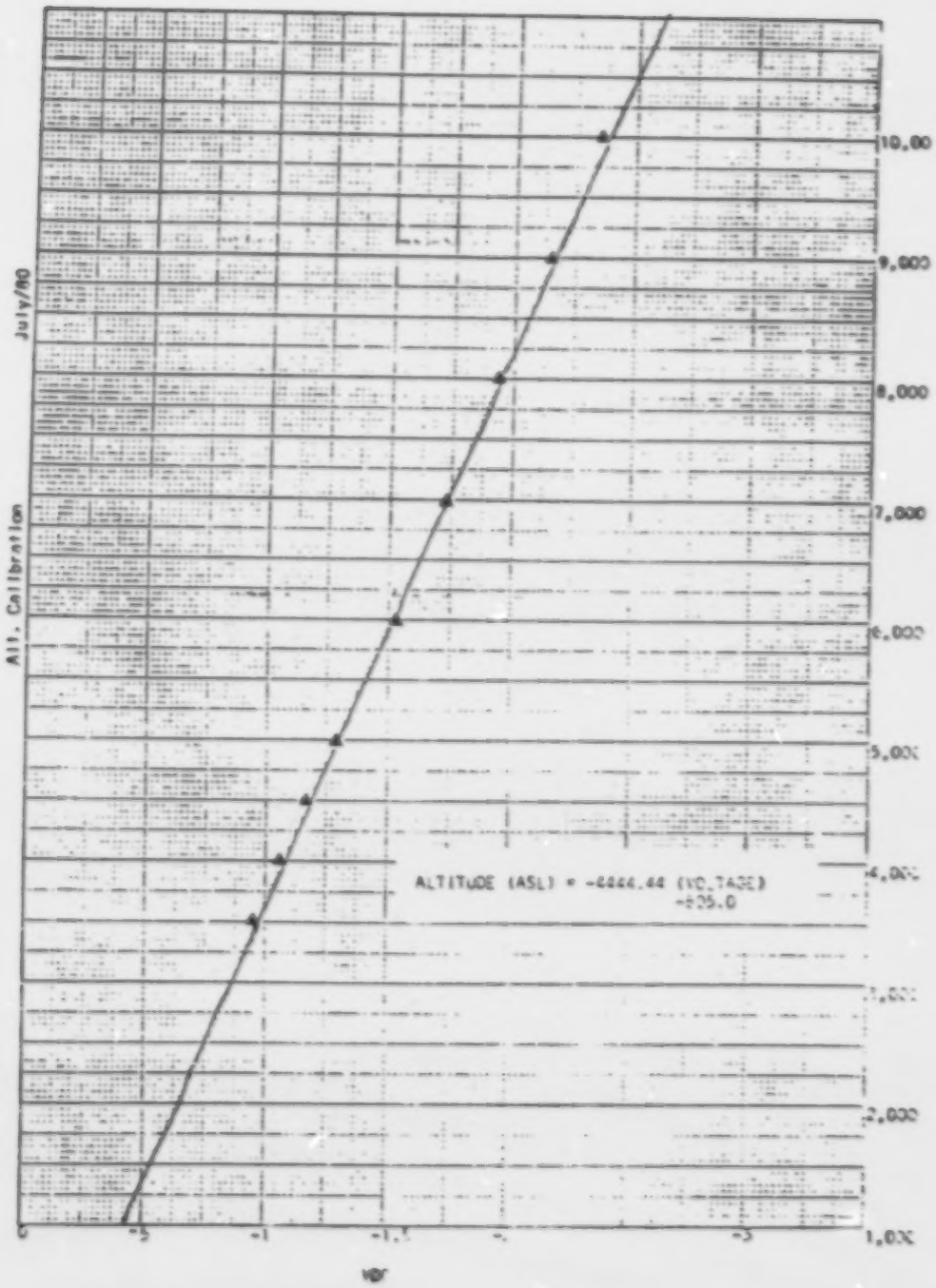


Figure 13. Calibration curve for INTERA's sensors.

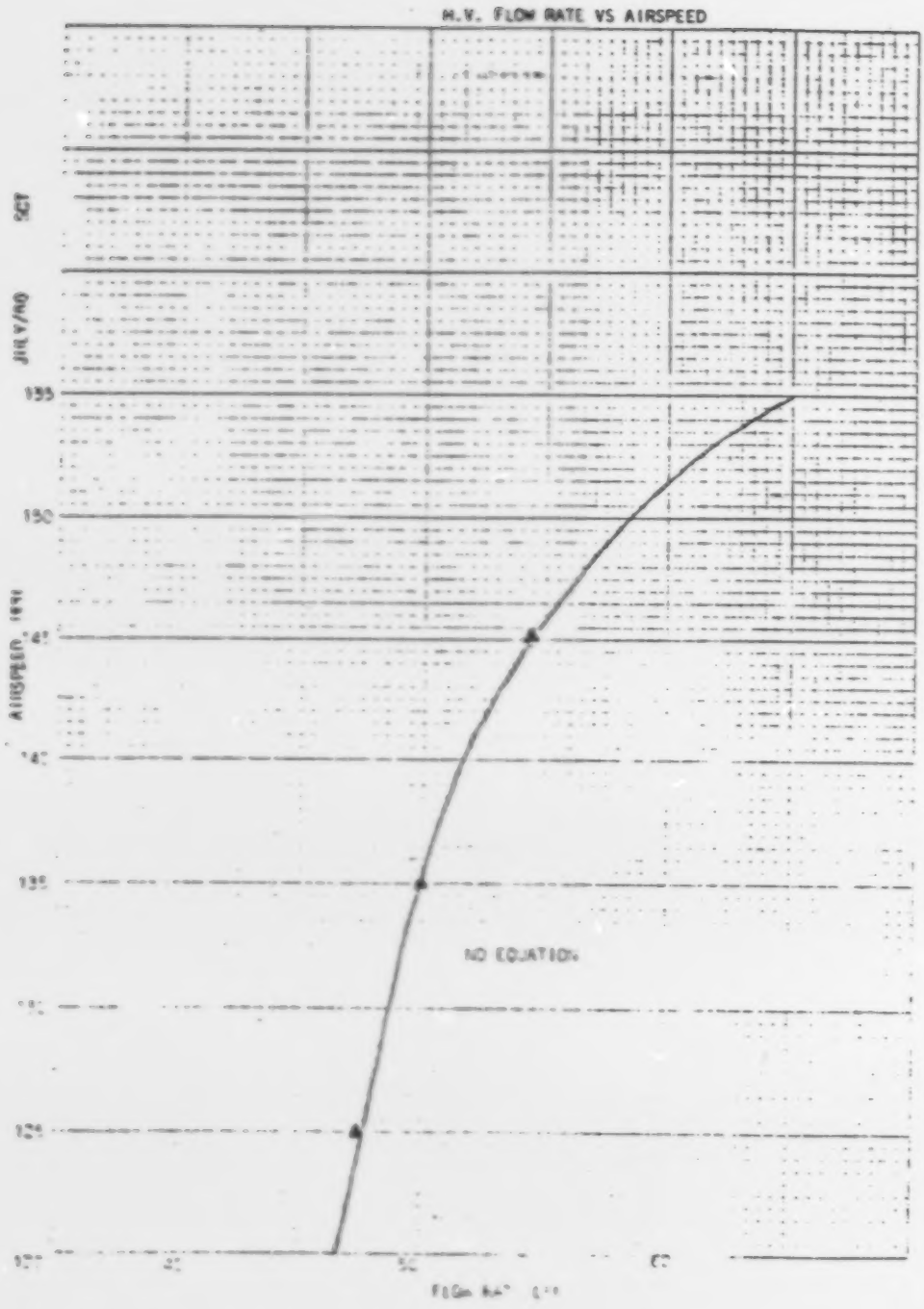


Figure 19. Calibration curve for INTERA's sensors.

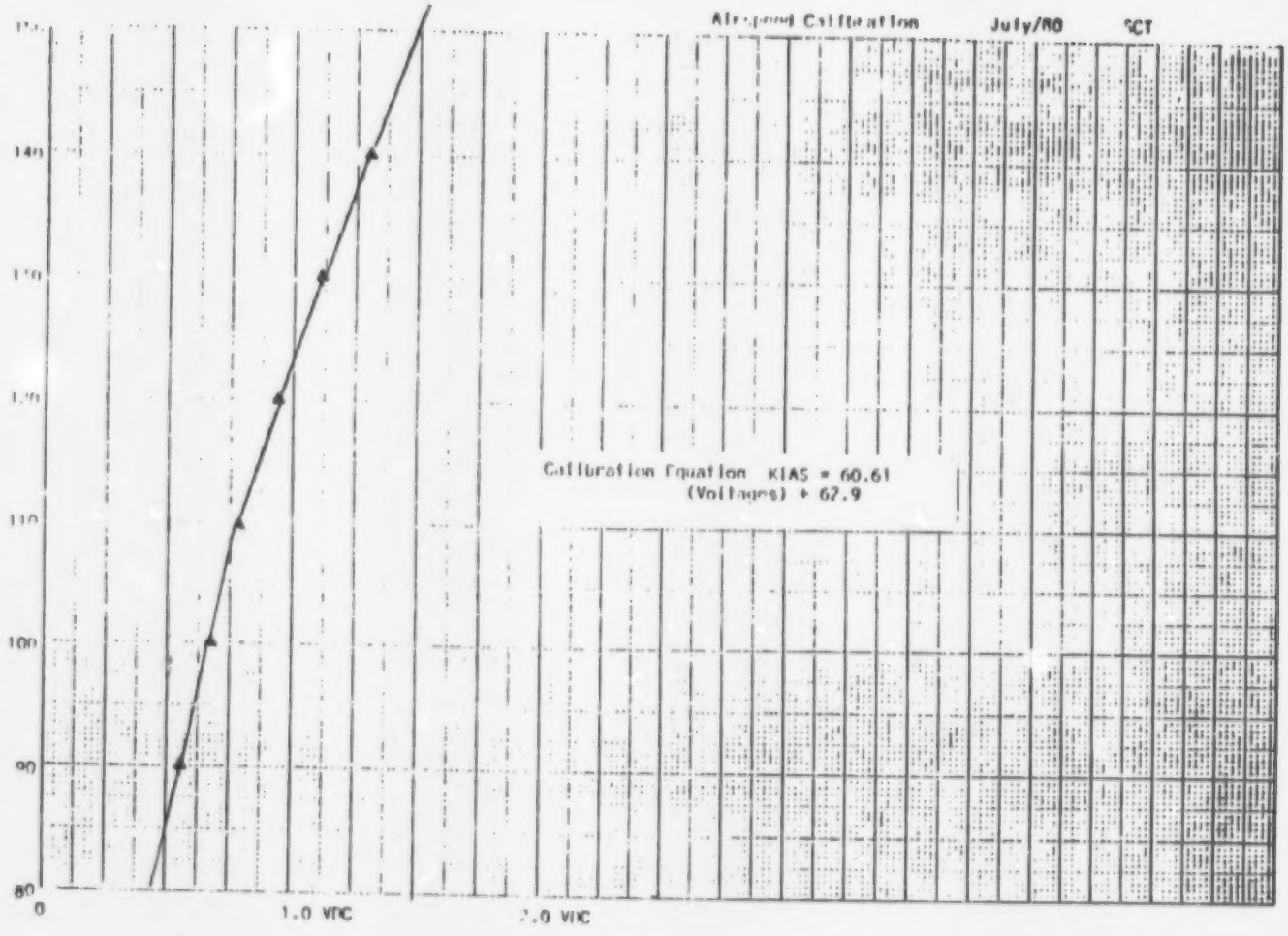


Figure 20. Calibration curve for INTERA's sensors.

Table 14. Summary of flight operations, January/March 1980.

DATE	TIME (MST)	HOURS	CUMULATIVE HOURS	MISSION NUMBER
Jan. 8	0930 to 1250	3.0	3.0	N/A - Ferry Flight
Jan. 9	0903 to 1241	3.6	6.6	009-80-1
Jan. 9	1730 to 1935	2.1	8.7	009-80-2
Jan. 10	1158 to 1400	2.0	10.7	010-80-1
Jan. 11	1312 to 1700	3.8	14.5	011-80-1
Jan. 13	1025 to 1330	2.9	17.4	013-80-1
Jan. 13	1510 to 1635	1.4	18.8	013-80-2
Jan. 13	1845 to 2145	3.0	21.8	N/A - Ferry Flight
Mar. 17	0915 to 1215	3.0	24.8	N/A - Ferry Flight
Mar. 18	1540 to 1750	2.2	27.0	078-80-1
Mar. 19	1716 to 1958	2.8	29.8	079-80-1
Mar. 20	0945 to 1435	4.8	34.6	080-80-1
Mar. 21	1150 to 1600	4.2	38.8	081-80-1
Mar. 21	1702 to 1930	2.5	41.3	081-80-2
Mar. 24	0857 to 1345	4.8	46.1	081-80-1
Mar. 25	0852 to 1150	3.0	49.1	084-80-1
Mar. 25	1259 to 1635	3.6	52.7	085-80-2
Mar. 25	1830 to 2130	3.0	55.7	N/A - Ferry Flight

Table 15. Summary of flight operation, June/July 1980.

Flight No.	Date	Time (MST)	Hours	Cumulative Hours	Purpose
177-80-1	June 25	1435 to 1625	2.0	2.0	Ferry to Fort McMurray
177-80-2	June 25	1630 to 1650	.5	2.5	Fuel Ferry
177-80-3	June 25	2035 to 2305	2.7	5.2	SO_2 and Sounding Test
180-80-1	June 28	1010 to 1022	.4	5.6	Fuel Ferry
180-80-2	June 28	1230 to 1540	3.4	9.0	Sampling
182-80-1	June 30	1515 to 1530	.4	9.4	Fuel Ferry
185-80-1	July 3	1400 to 1415	.4	9.8	Fuel Ferry
186-80-1	July 4	1000 to 1350	4.0	13.8	Sampling
187-80-1	July 5	0505 to 0845	3.9	17.7	Sampling
187-80-2	July 5	0920 to 0950	.6	18.3	Sampling
187-80-3	July 5	1630 to 1645	.4	18.7	Fuel Ferry
189-80-1	July 7	0510 to 0730	2.4	21.1	Sampling
189-80-2	July 7	1030 to 1205	1.8	22.9	Sampling
189-80-3	July 7	1230 to 1240	.4	23.3	Fuel Ferry
189-80-4	July 7	1340 to 1605	2.5	25.8	Sampling
189-80-5	July 7	1655 to 1705	.4	26.2	Fuel Ferry
189-80-6	July 7	1805 to 1930	1.6	27.8	Sampling
190-80-1	July 8	1005 to 1235	1.7	29.5	Sampling
190-80-2	July 8	1245 to 1300	.4	29.9	Fuel Ferry
190-80-3	July 8	1330 to 1340	.4	30.3	Fuel Ferry
190-80-4	July 8	1345 to 1635	2.7	33.0	Sampling
190-80-5	July 8	1645 to 1700	.4	35.5	Ferry to Calgary

case days, along with the location and plume source, where known. Included in these samples were several background cases to document the airshed upstream of the sources.

In addition to the meteorological data that were collected in the field, the Research Management Division obtained some wind data from the Syncrude acoustic sounder and the Alberta Environment tall tower. These data have been examined and included in the case studies, where applicable.

The January cases were all characterized by extreme cold conditions (typically -20° to -30° at the surface) with strong inversions aloft. The plume behaviour was generally very similar, with very little vertical mixing. There were no cases with the plumes penetrating the inversion level, nor were there any cases of fumigation mixing down to the surface. One case study was unique in that the plume was emitted into an ice fog regime.

The March cases were characterized by more moderate late winter conditions with surface temperatures a few degrees below freezing. Plume behaviour was once again rather constant with more vertical mixing than in January, but still in a stable boundary layer. Only on March 25 was the plume sampled in a neutral boundary layer and there was some evidence of plume fumigation evident.

The July cases were all characterized by typical summer synoptic situations, which ranged from stable boundary layers that resulted from the formation of nocturnal inversions to mid-afternoon fumigation to the surface. Also, there was evidence of unusually high concentrations of ozone downwind from the sources that have been described as "ozone bulges" to the plume.

6.2.1 1980 January 09

The aircraft was launched on this first mission to sample the plumes to the east of the Oil Sands region. During the first hour of operations attempts were made to intercept the plume at considerable distances downwind from the source. However, due to relatively strong winds the plume was well mixed, and only occasionally was the plume encountered.

The aircraft was then repositioned closer to the Suncor plant, approximately eight miles downwind, and a series of transects was flown through the Suncor plume. Filters 2 and 3 were exposed during this period. Figure 21 shows the location of the plume transects, as well as the location of the background sample. Table 16 summarizes the exposure times and comments regarding the samples. Note that the flow rate for the filter system is in litres per minute, and based on a calibration conversion of 1.0 vdc = 10 l $min.^{-1}$.

The general synoptic pattern for the cases in early January was a deep, cold surface layer under an upper level high pressure system. Surface winds were light, and the temperatures were typically colder than -20°C. Table 17 is the surface weather observation sequence at the Fort McMurray airport for the times of interest. Note the good visibility and the light winds.

During the flight the aircraft conducted a temperature sounding from the surface to 9000' MSL. As mentioned earlier, the airborne data acquisition system was unrealiable; however, the onboard technician recorded the temperature during the ascent. Figure 22 depicts the aircraft sounding along with the airport surface observation for 1100 hours. Also shown is the winds aloft hodograph from the nearest in time observation from the airport.

The hodograph is a graphical presentation of the wind vectors at the depicted heights above the surface. In this case, the surface winds are shown from the west at approximately 5 kts, while above 2000' the winds have increased to 20 kts. The temperature profile shows the deep inversion between the surface and 3000' MSL.

A second case was flown on 09 January, under conditions only slightly changed from the earlier flight. Surface weather observations, shown in Table 17, still revealed clear visibility, cold temperatures, and light winds. Note that the barometer pressure had been steadily dropping throughout the day. The Fort McMurray 1700 hodograph, shown in Figure 23, indicated that the low-level winds had shifted slightly to the southwest, while the upper winds were unchanged from earlier in the day.

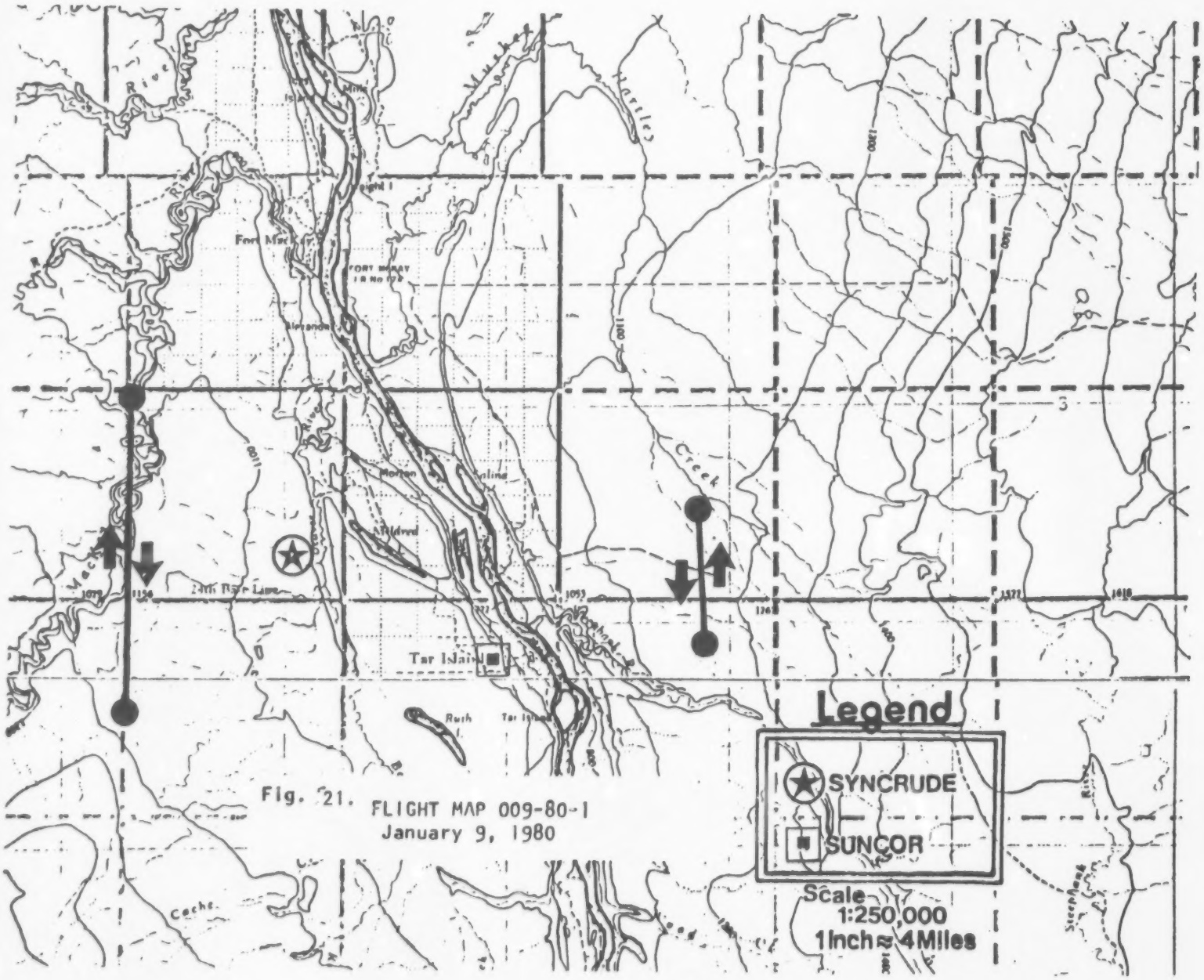


Fig. 21. FLIGHT MAP 009-80-1
January 9, 1980

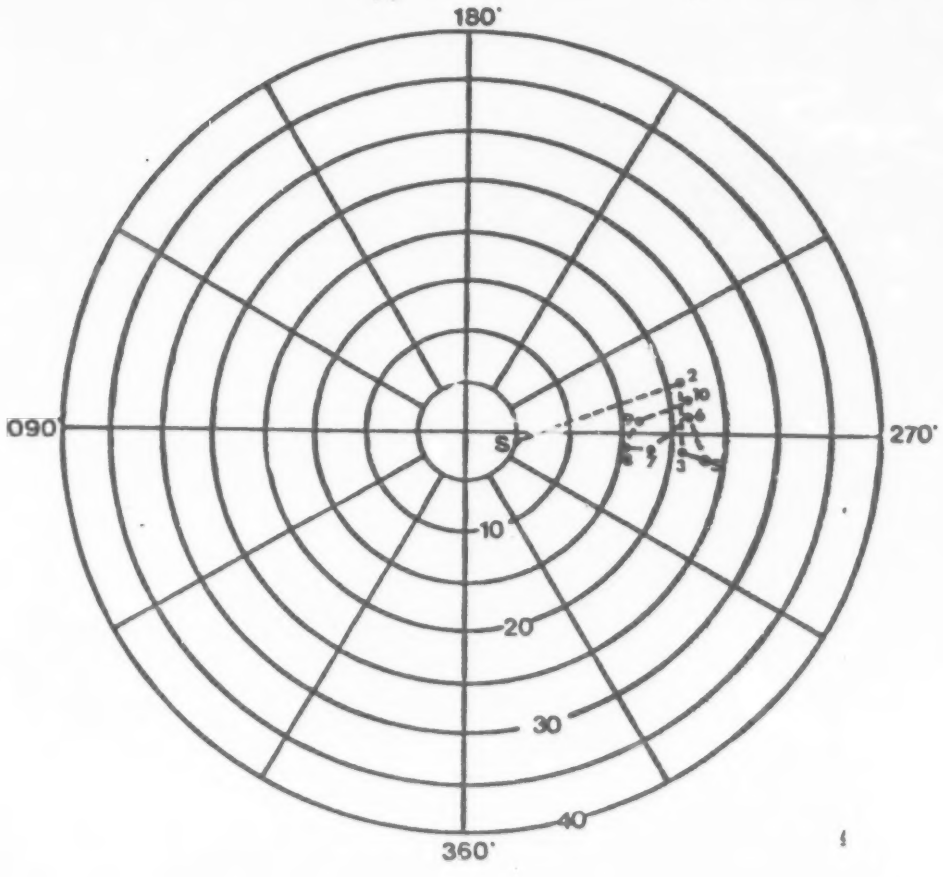
Table 16. Summary of measurements, 1980 January 09.

CASE NO. 009-80-1

SAMPLE NO.	EXPOSURE TIMES	LOCATION (BEARING FROM n.mi)	SOURCE	ALTITUDE (FEET)	TEMP. (^{o}C)	FILTER FLOW RATE (l/m)	HI-VOL FLOW RATE (cfm)	REMARKS
Filter #1	N/A							
Filter #2	1043-1103	070/8	Suncor	2000'	-26	19.5-19.0	N/A	Flight was circular orbit to stay in plume.
Filter #3	1105-1126	070/8	Suncor	2000'	-26	19.6-18.9	N/A	Six transects
Filter #4	1132-1153	280/10	Background	2000'	-26	19.5-19.6	N/A	Upwind background sample. O_3 level constant 0.02 ppm.
Air Sample #1	1053-1056	070.8	Suncor	2000'	-26	N/A	N/A	Bag destroyed during temperature sounding.

Table 17. Fort McMurray surface weather observations, 1980 January 09.

TIME (MST)	TEMPERATURE (^{o}C)	DEW POINT (^{o}C)	VISIBILITY (MILES)	WIND DIRECTION (^{o}TRUE)	WIND SPEED (KTS)	PRESSURE (INCH)
0800	-30	-33	15	210	03	29.94
0900	-31	-34	12	220	03	29.91
1000	-29	-34	12	260	05	29.90
1100	-28	-33	12	250	07	29.89
1200	-27	-29	12	210	12	29.86
1300	-25	-30	12	220	10	29.81
1700	-26	-28	15	00	00	29.77
1800	-26	-29	15	200	04	29.75
1900	-27	-29	15	210	03	29.74
2000	-27	-30	15	230	02	29.73



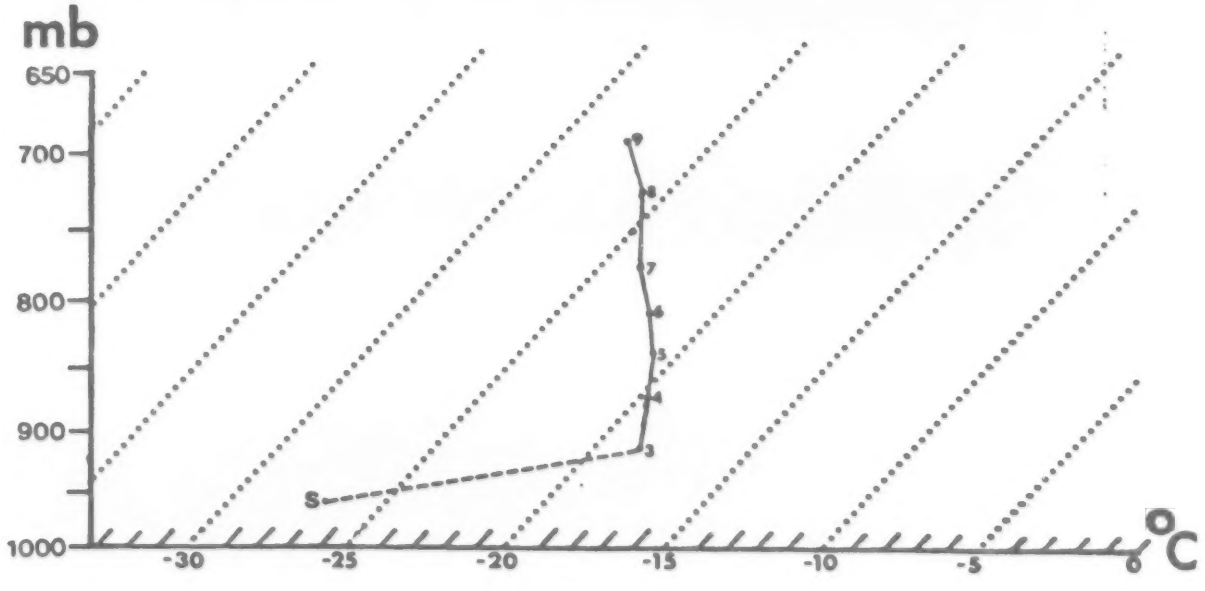
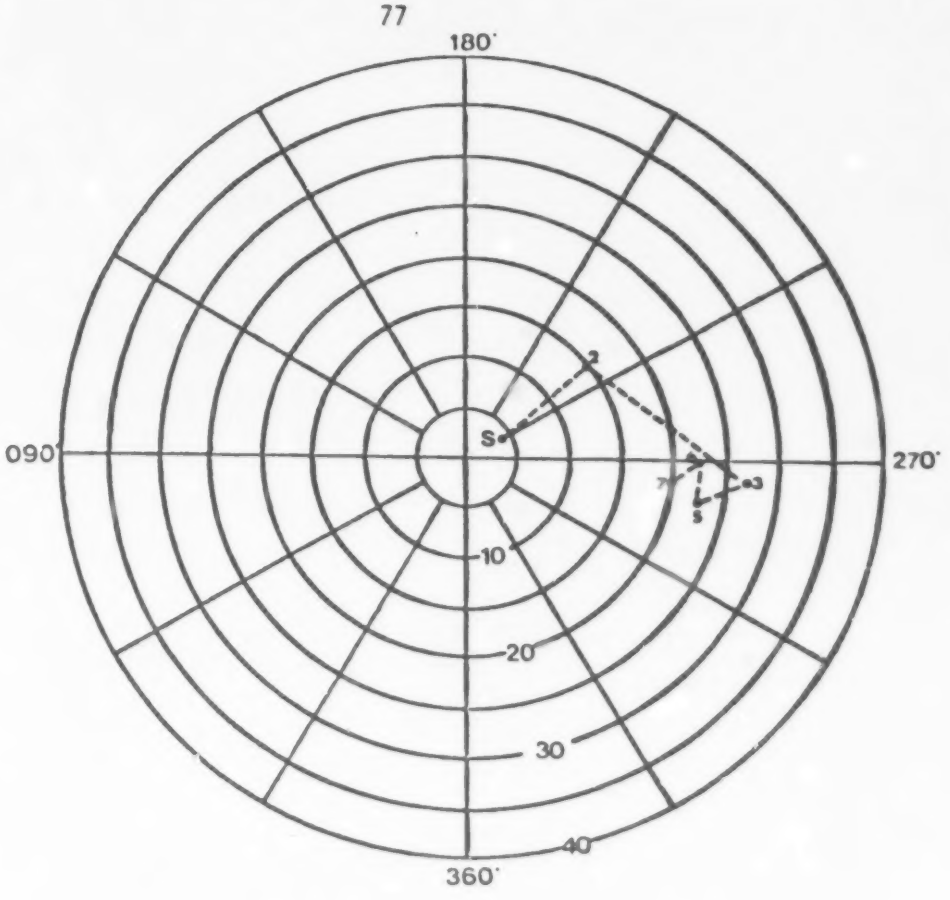


Figure 22. Hodograph & Temperature Sounding
Jan. 9, 1980

Hodograph 1100 hrs.
Sounding 1200 hrs.



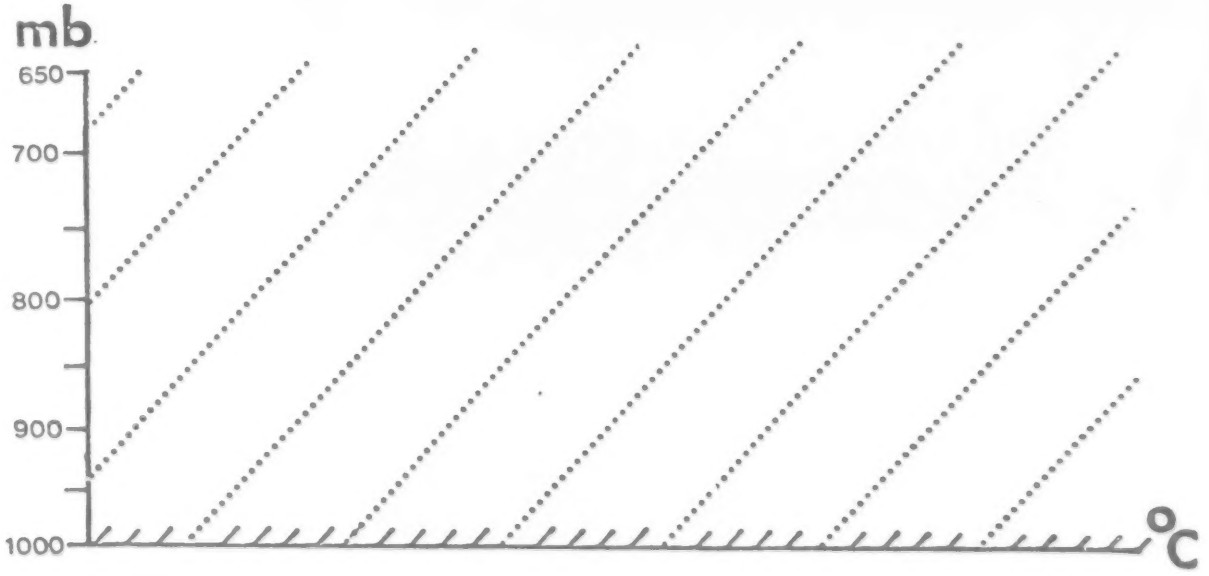


Figure 23. Hodograph
Jan. 9, 1980. 1700 hrs.

The aircraft conducted two sets of transects of the plume Syncrude and one background sample, as shown in Figure 24. The first series of transects was conducted approximately 6 miles east of the plant, at an altitude of 2500' MSL. The Suncor plume was observed to be below the flight altitude, and tracking more easterly than the Syncrude plume, so there was no likelihood of interference between the two plumes. Table 18 presents the details of the air samples.

No temperature sounding was conducted during the evening runs. However, it was assumed that the earlier sounding was still representative. The background sample was conducted approximately 3 miles upwind of the Syncrude plant, at the same altitude as the plume transects. The flight was terminated due to darkness following the background samples.

6.2.2 1980 January 10

One case study was flown on 10 January that gathered filter samples from the Syncrude plant, as shown in Figure 25. The aircraft was launched at 1150 hours, under conditions of limited visibility due to ice crystals and ice fog. Table 19 shows the surface weather observations for the period of aircraft operations. Note the restrictions to visibility and to the light winds and small temperature-dew point difference.

Throughout the flight, there were visibility problems due to the ice fog. Furthermore, while sampling the plume, the high water content that was being released resulted in ice formation on the air intake and venturi exhaust systems. Table 20 presents the pertinent remarks for the filter and air samples, and notes the reduced flow rate during the sampling runs.

Following the plume transects the aircraft conducted a temperature sounding up to 10 000' MSL. This sounding and the corresponding wind hodograph from the airport are presented in Figure 26. Also plotted on the temperature profile is the surface temperature observation from the airport. Note the very deep inversion between the surface and 3000' MSL, followed by an isothermal layer up to

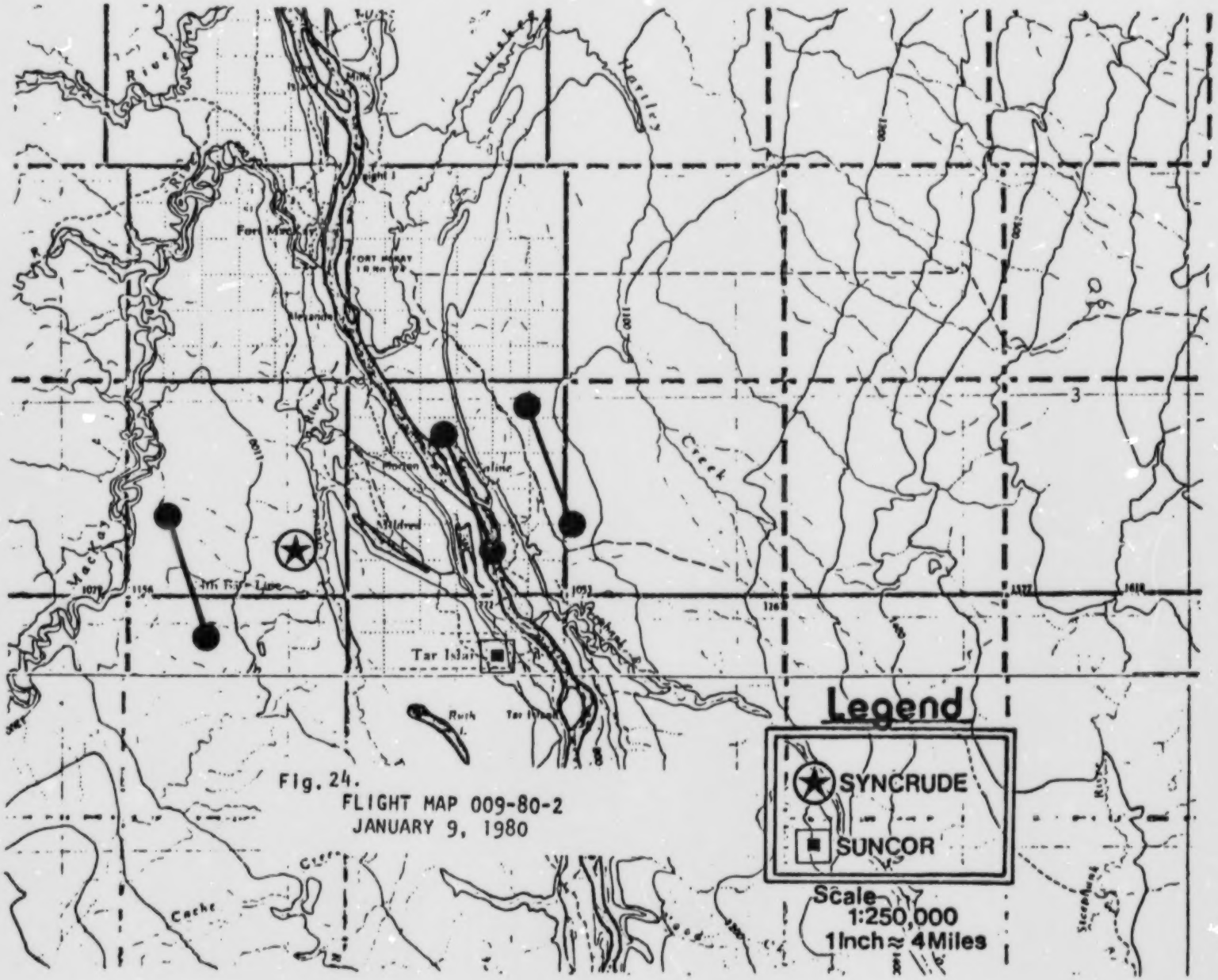


Fig. 24.
FLIGHT MAP 009-80-2
JANUARY 9, 1980

Table 18. Summary of measurements, 1980 January 09.

CASE NO. 009-80-2

SAMPLE NO.	EXPOSURE TIMES	LOCATION (BEARING FROM n.mi)	SOURCE	ALTITUDE (FEET)	TEMP. (°C)	FILTER FLOW RATE(l/m)	HI-VOL FLOW RATE(cfm)	REMARKS
Air Samples #1	1740-1750	080/4	Syncrude	2500'	-23	N/A	N/A	Opened during plume encounter while flying over the River.
Filter #1	1755-1815	080/6	Syncrude	2500'	-23	25.0-24.0	N/A	10 Transects
Filter #2	1817-1838	080/4	Syncrude	2500'	-23	24.0-23.5	N/A	11 Transects
Filter #3	1840-1900	260/3	Background	2500'	-22	24.5-24.5	N/A	

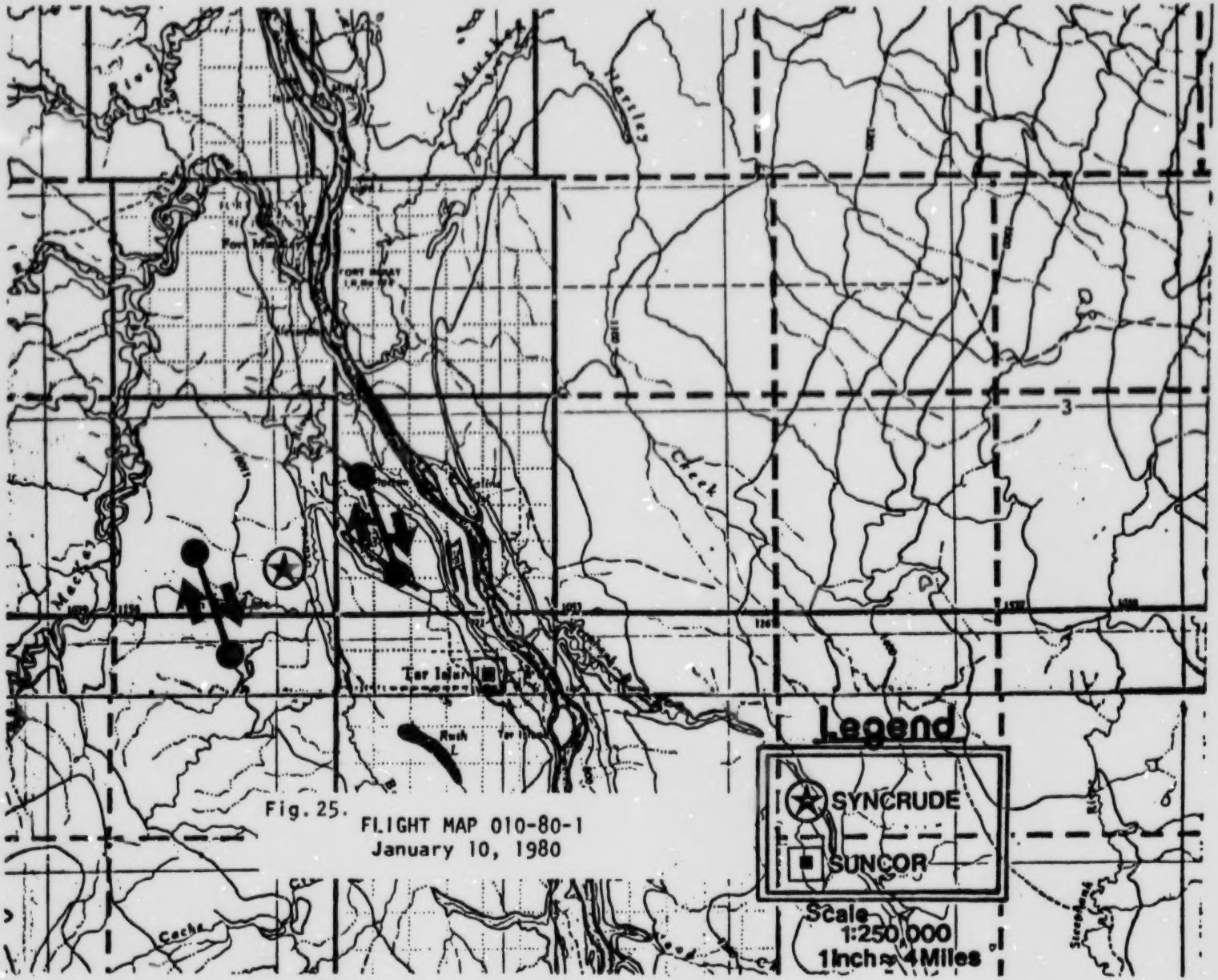


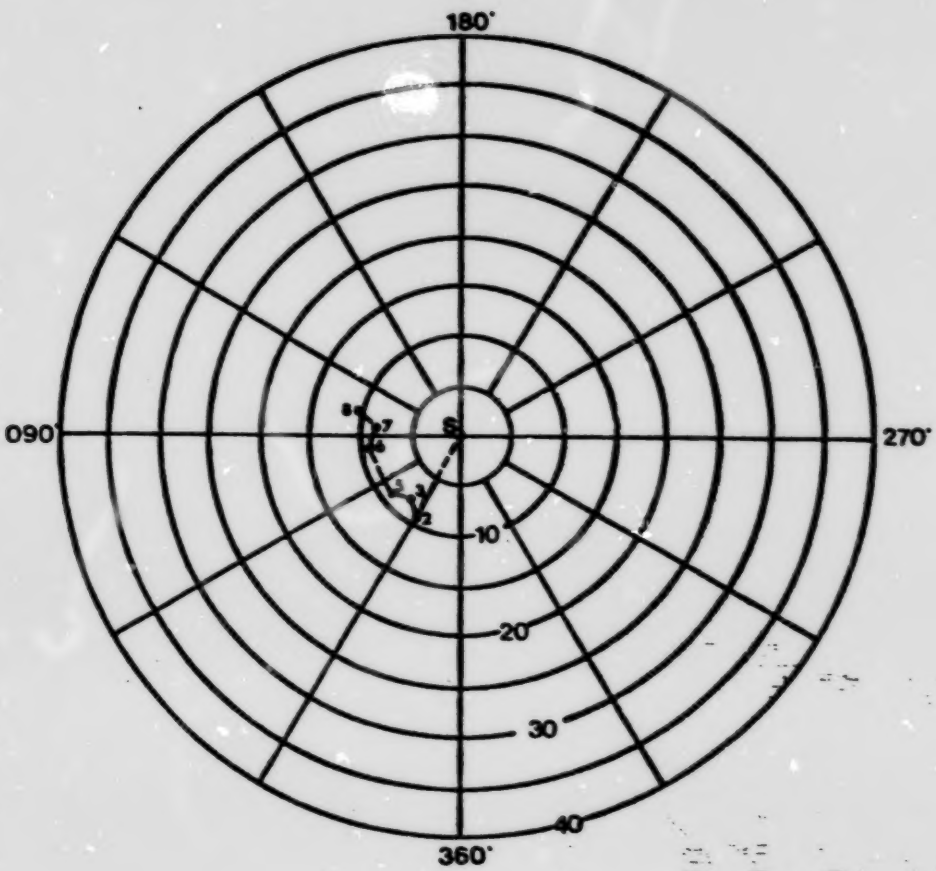
Fig. 25. FLIGHT MAP 010-80-1
January 10, 1980

Table 19. Fort McMurray surface weather observations, 1980 January 10.

TIME (MST)	TEMPERATURE (^{o}C)	DEW POINT (^{o}C)	VISIBILITY (MILES)	WIND DIRECTION (^{o}TRUE)	WIND SPEED (KTS)	PRESSURE (INCH)
1100	-32	-35	2ICIF	00	00	29.85
1200	-32	-35	6ICIF	270	02	29.87
1300	-31	-34	IOIF	290	05	29.87
[illegible]	-30	-33	2ICIF	280	03	29.58

Table 20. Summary of measurements, 1980 January 10.

						CASE NO. 010-80-1		
SAMPLE NO.	EXPOSURE TIMES	LOCATION (BEARING FROM n.mi)	SOURCE	ALTITUDE (FEET)	TEMP. (°C)	FILTER FLOW RATE (l/m)	HI-VOL FLOW RATE (cfm)	REMARKS
Filter #1	1242-1307	260/3	Syncrude	2500'	-27	20.0-1.5	N/A	10 Transects of plume, in ice fog. 2 miles visibility. Flow over filter clogged with ice crystal.
Filter #2	1339-1354	090/3	Background	2500'	-27	15.6-3.5	N/A	Filter exposure upwind of plant, note flow rate, due to intake and venturi icing.
Air Sample #1	1302-1307	260/3	Syncrude	2500'	-27	N/A	N/A	Opened only during plume encounter
Air Sample #2	1343-1347	090/3	Background	2500'	-27	N/A	N/A	Upwind sample.



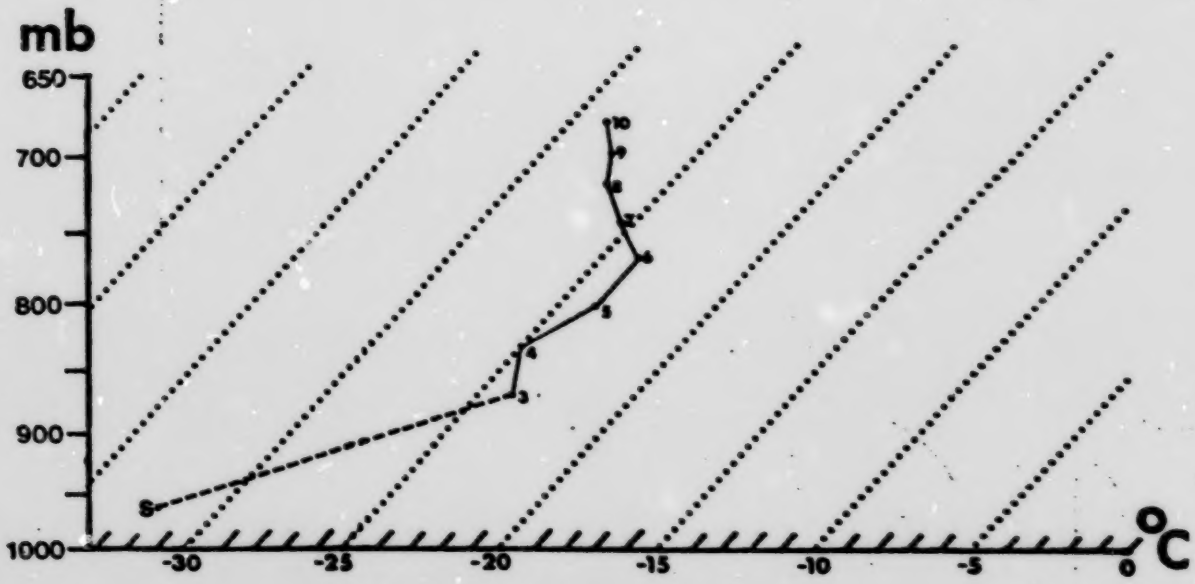


Figure 26. Hodograph & Temperature Sounding
Jan. 10, 1980

Sounding 1130
Hodograph 1100

6000'. The wind profile revealed a steady 10 kt wind that backed from 2000' through 8000' and suggested an advection of cold air into the Fort McMurray region. The ice fog was observed to extend up through 10 000' during the sounding.

Following the sounding, the aircraft conducted a background sampling run approximately 5 miles upwind of the Syncrude plant. There was a similar icing problem for this sample set, and the mission was terminated after the background run.

6.2.3 1980 January 11

The aircraft was launched at 1300 hours to conduct additional plume sampling runs. On this day four sets of transects were conducted, as shown in Figure 27. The first set concentrated on the Syncrude plume, approximately 2 miles downwind from the stack. There was a similar icing problem that was encountered on 10 January, but not as severe. As shown in Table 21, there were not restrictions to visibility; however, the ambient temperature was still very cold with calm surface winds. Table 22 summarizes the measurements for this case.

The plume on this day was quite visible near the source and showed an unusual change of phase from predominently liquid near the source to ice crystals beyond 3 miles downwind.

The second set of transects was conducted approximately 8 miles downwind from the Syncrude stack, at the same altitude as the earlier set. Venturi icing continued to be a problem which resulted in reduced flow rate through the filter pack.

The Suncor plume was observed to be somewhat lower in altitude than the Syncrude plume, and was still distinct from the Sycrude one. It was decided to conduct a series of transects of the Suncor plume at a downwind distance comparable to the second Syncrude set, in order to compare the two. Maximum plume concentration height was around 2000' MSL for this set.

The final set of transects was conducted on the Syncrude plume approximately 15 miles downwind of the plant, as shown in Figure 27.

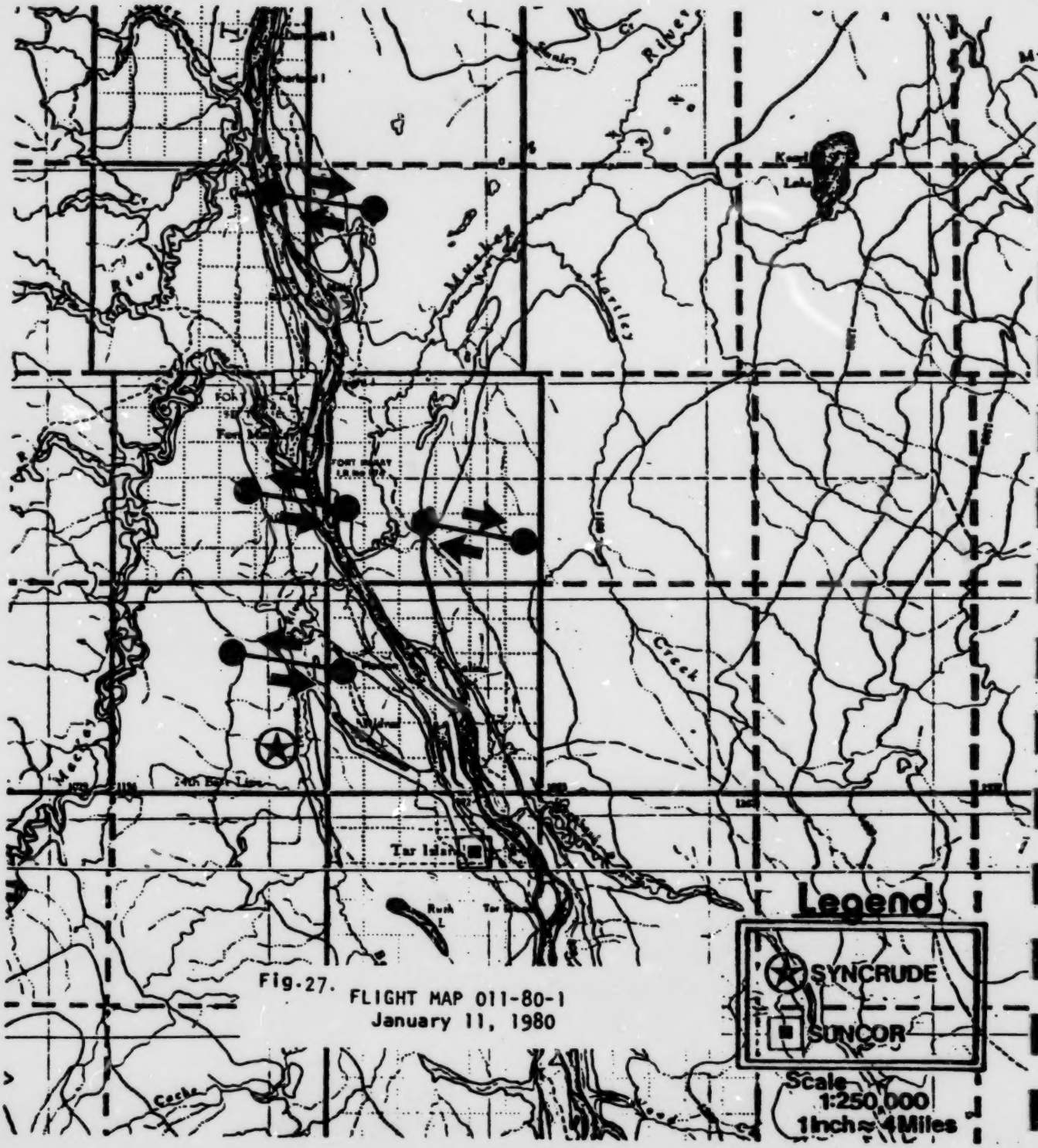


Fig.27. FLIGHT MAP 011-80-1
January 11, 1980

Table 21. Fort McMurray surface weather observations, 1980 January 11.

TIME (MST)	TEMPERATURE (^{o}C)	DEW POINT (^{o}C)	VISIBILITY (MILES)	WIND DIRECTION (^{o}TRUE)	WIND SPEED (KTS)	PRESSURE (INCH)
1300	-35	-38	10	00	00	30.05
1400	-35	N/A	10	00	00	30.02
1500	-34	N/A	10	00	00	30.01
1600	-34	N/A	10	00	00	30.00
1700	-32	-37	10	070	04	29.32

Table 22. Summary of measurements, 1980 January 11.

CASE NO. 011-80-1

Sample No.	Exposure Times	Location (Bearing from n.mi)	Source	Altitude (Feet)	Temp. (C°)	Filter Flow Rate (l/m)	Hi-Vol Flow Rate (cfm)	Remarks
Filter #1	1357-1419	010/2	Syncrude	2800'	-26	21.0-4.0	N/A	14 Transects over Mildred Lake Airport. Had same problem of ice crystals clogging the filters, bit not as bad as Jan. 10 case.
Filter #2	1430-1502	010/8	Syncrude	2600'	-26	6.8-2.5	N/A	15 Transects. Note low flow rate due to ice-up venturi.
Filter #3	1505-1531	360/10	Suncor	2000'	-26	10.0-9.8	N/A	11 Transects of Suncor plume. Slightly higher sulphur readings than in the Syncrude plume.
Filter #4	1540-1613	010/15	Syncrude	1800'	-26	10.5-10.5	-	13 Transects.

continued ...

Table 22. Concluded.

Filter #5	1646-1700	180/3-5	Background	-	-	1.5-1.5	-	Background flight between Mildred Lake and Fort McMurray. Flow rate could not be increased. Suspect filter problem.
Air Sample #1	1400-1410	010/2	Syncrude	2800'	-26	-	-	Was exposed with Filter #1 during passes 2-6. Only opened while in plume.
Air Sample #2	1430-1445	010/8	Syncrude	2600'	-26	-	-	Was exposed with Filter #1 during passes 1-7. Also opened only while in plume.
Air Sample #3	1540-1544	010/15	Syncrude	1800'	-26	-	-	Was exposed with Filter #3 during passes 1-2.

Afterwards, a background sample was collected while the aircraft was flown between Mildred Lake and Fort McMurray.

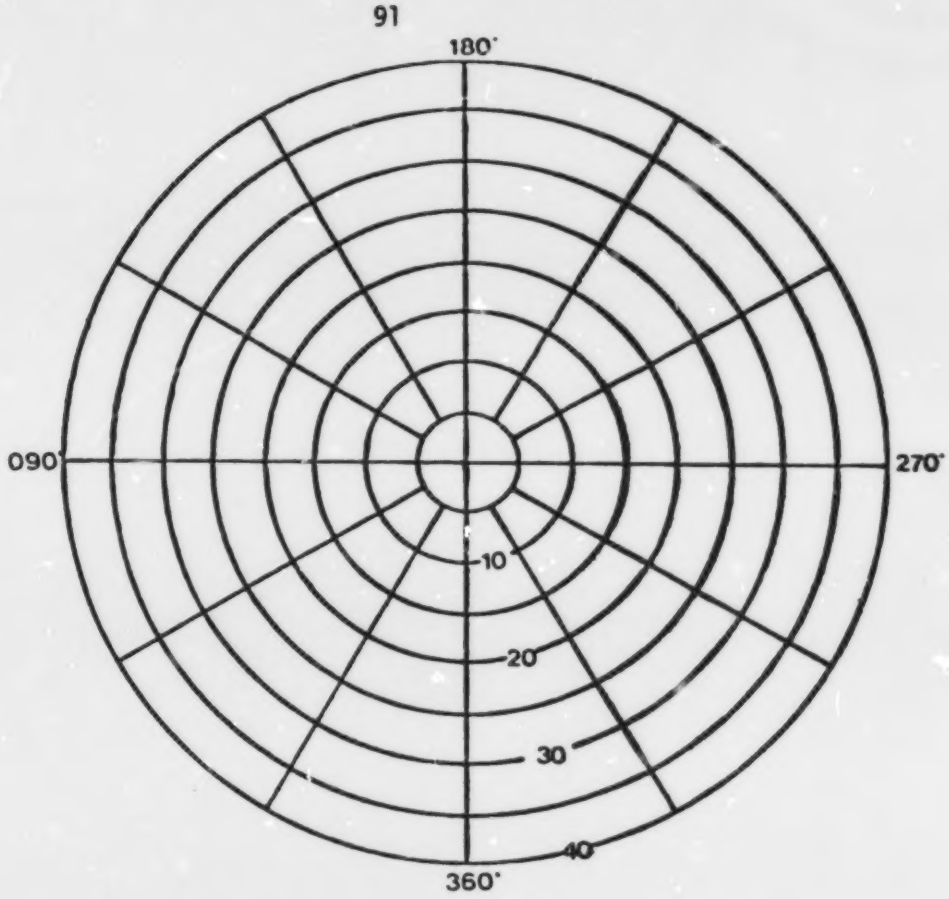
An aircraft temperature sounding was conducted at 1300 hours and is presented in Figure 28. Note the deep surface inversion, capped by an isothermal layer between 3000' and 6000'. The entire temperature profile is cooler than the profile of 10 January, as suggested by the cold air advection (see Figure 26). There was no hodograph profile available for this case day.

6.2.4 1980 January 13

Two case studies were conducted on this day, one in the mid-morning, and the second one in the afternoon. Figure 29 shows the locations of the three plume transects of the Syncrude plume, which was seen to track to the northeast. The hodograph, however, revealed a southeasterly wind in the low-levels, as seen in Figure 30. The temperature profile, on the same figure, still showed a very strong inversion between the surface and 4000' MSL, capped by an isothermal layer several thousand feet deep. Note, however, the warming of the air mass that took place between 11 January and 13 January.

Table 23 summarizes the surface weather observations at the airport weather station. The weather was generally clear, with 15 miles visibility; however, the pressure field steadily dropped during the day. The surface temperature increased during the day, as a result of increased mixing due to the surface winds. Note the hodograph (Figure 31) for 1700 hours, with a 15 kt surface wind from the east, and a very strong southwesterly flow aloft. This profile suggested a warm airmass advection above 3000', although no sounding was taken to verify this.

Table 24 presents the measurements of this case. After the last series of plume traverses, the aircraft conducted a background sampling run from a point west of Bitermount to abeam the Syncrude plant. At one point during this run, there was evidence of plume encounter, with an increase in the SO_2 monitor.



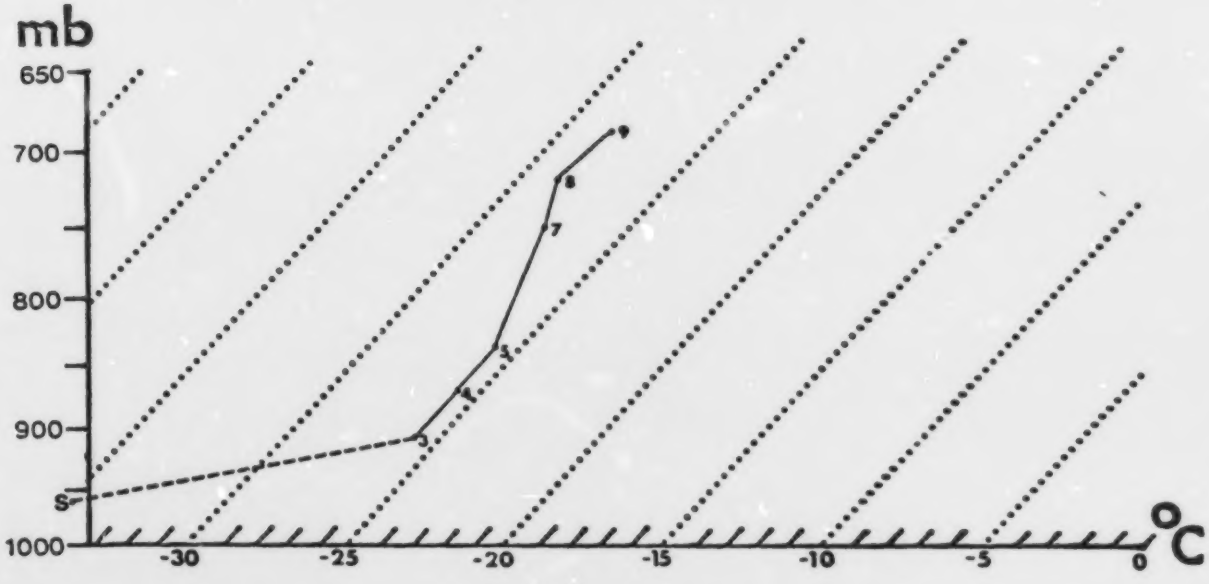


Figure 28. Temperature Sounding
Jan. 11, 1980. 1320 hrs.

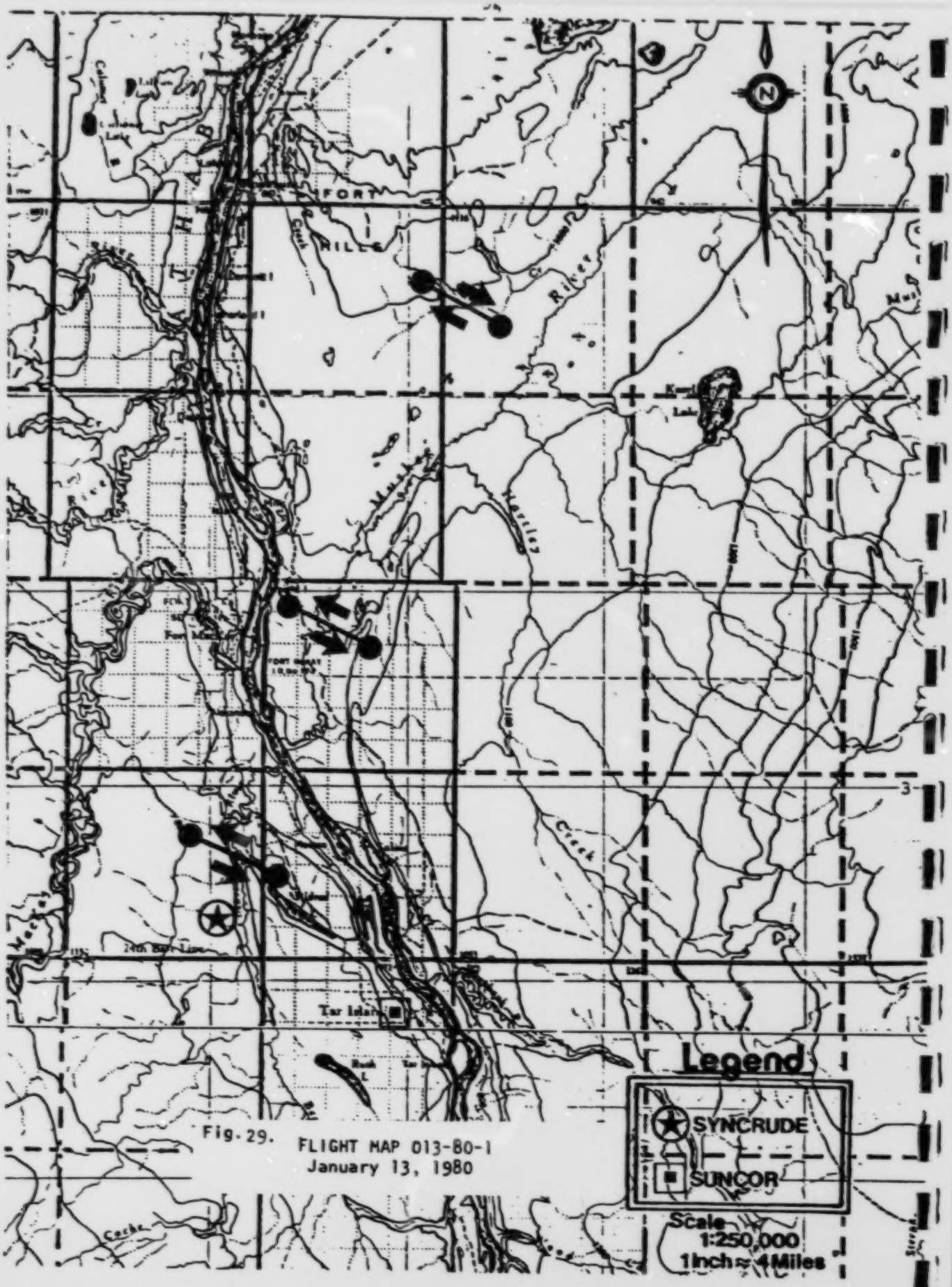
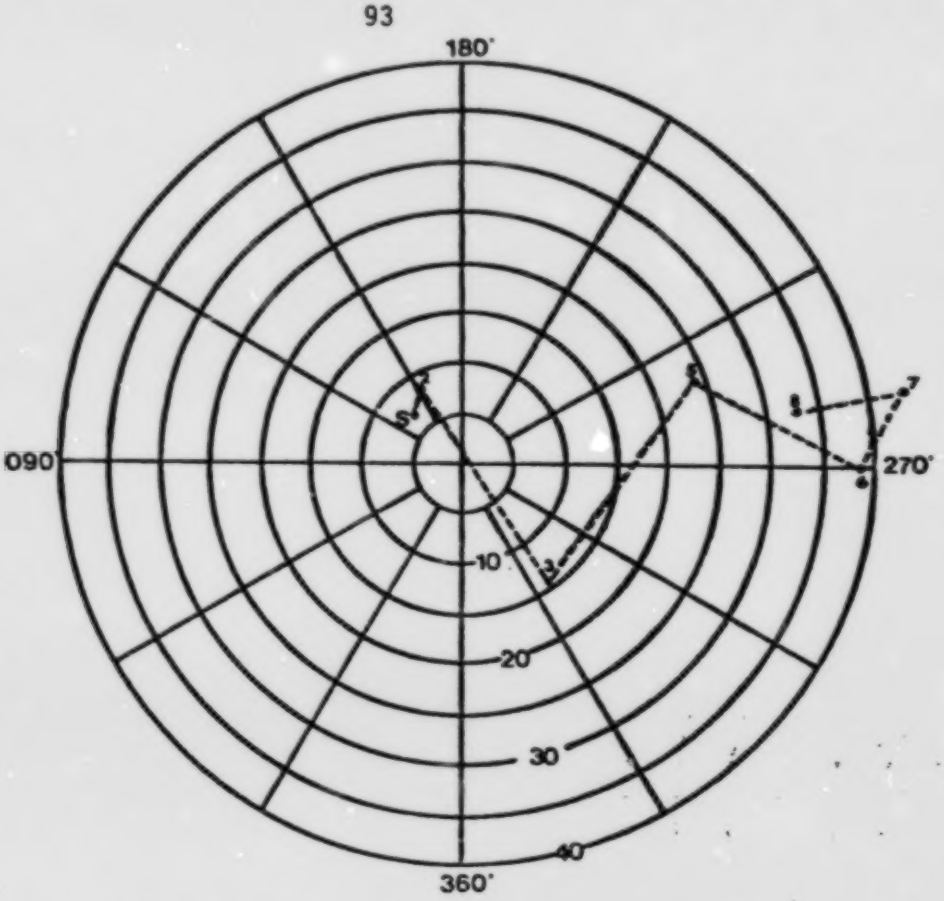


Fig. 29. FLIGHT MAP 013-80-1
January 13, 1980



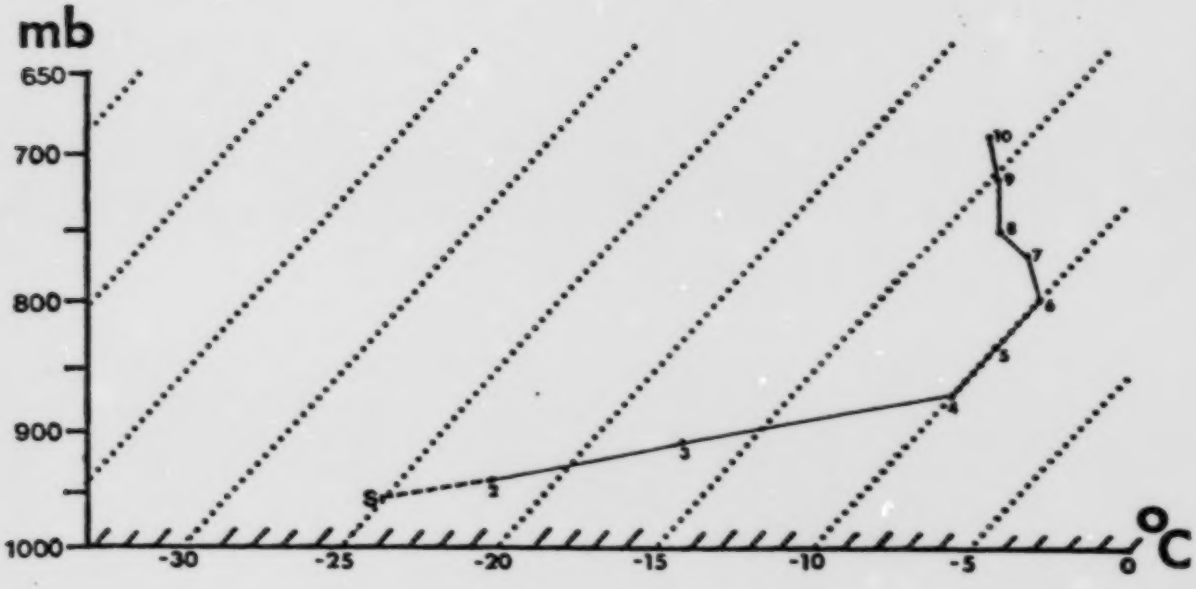


Figure 30. Hodograph & Temperature Sounding

Jan. 13, 1980

Sounding 1030
Hodograph 1100

Table 23. Fort McMurray surface weather observations, 1980 January 13.

TIME (MST)	TEMPERATURE (^{o}C)	DEW POINT (^{o}C)	VISIBILITY (MILES)	WIND DIRECTION (^{o}TRUE)	WIND SPEED (KTS)	PRESSURE (INCH)
1000	-27	-32	15	120	08	29.48
1100	-25	-30	15	080	07	29.45
1200	-23	-29	15	100	05	29.45
1300	-22	-28	15	080	09	29.45
1400	-21	-28	15	100	08	29.40
1500	-18	-24	15	100	10G19	29.34
1600	-18	-23	15	080	11G18	29.32
1700	-18	-23	15	070	07	29.30

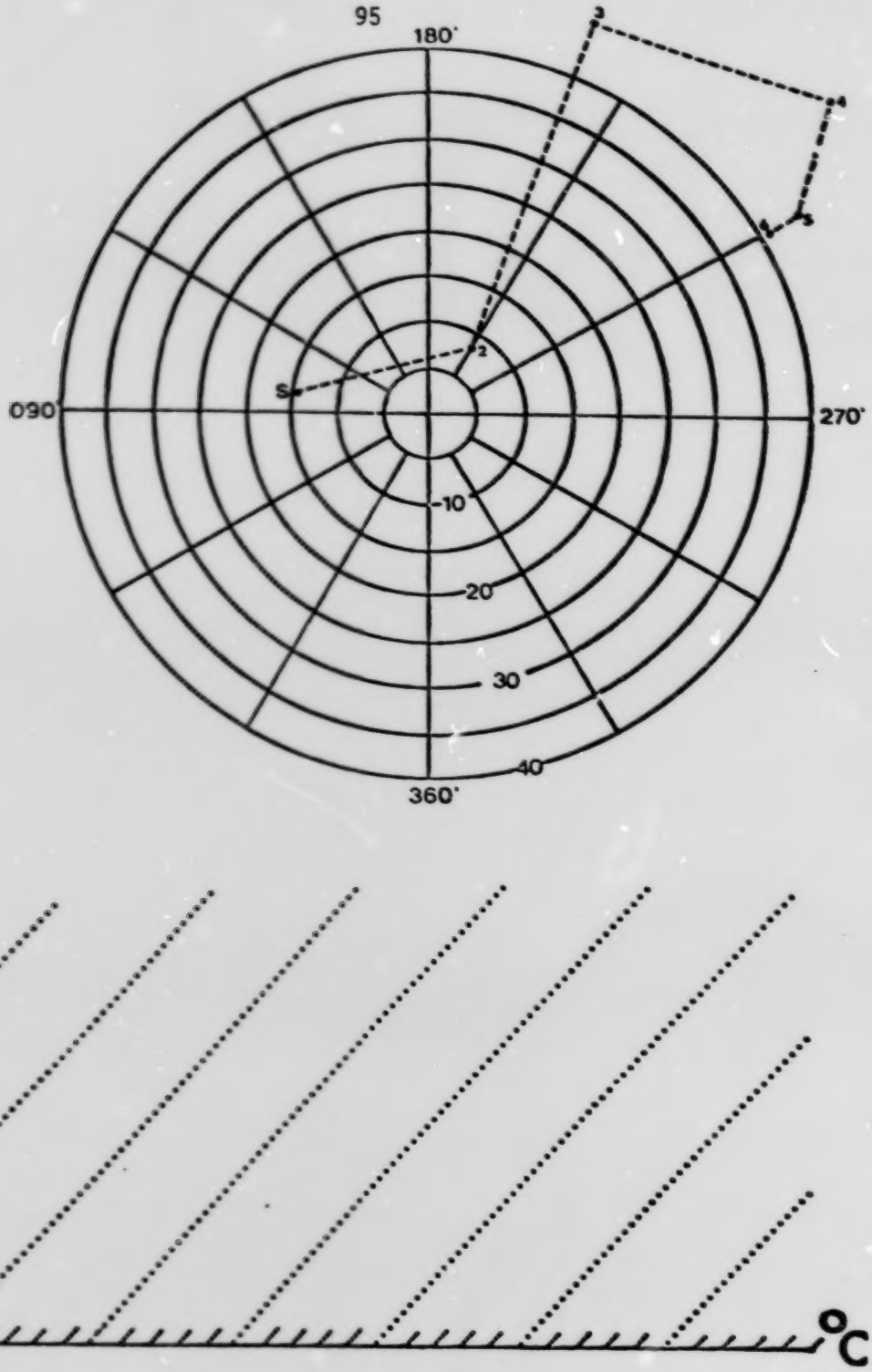


Figure 31. Hodograph

Jan. 13, 1980. 1700 hrs.

Table 24. Summary of measurements, 1980 January 13.

CASE NO. 013-80-1

Sample No.	Exposure Times	Location (Bearing (from n.mi)	Source	Altitude (Feet)	Temp. (C^0)	Filter Flow Rate (l/m)	Hi-Vol Flow Rate (cfm)	Remarks
Filter #1	1106-1130	015/2	Syncrude	2400'	-20	21.0-17.0	N/A	20 Transects through the Syncrude plume.
Filter #2	1139-1211	015/10	Syncrude	2600'	-20	18.0-18.5	N/A	11 Transects.
Filter #3	1216-1251	015/20	Syncrude	2600'	-19	20.5-19.0	N/A	9 Transects.
Filter #4	1253-1308	260/20-3	Background	2500'	-19	18.0-19.0	N/A	Background run from Bitermount to west of Syncrude plant. Appeared to be well west of plume except one encounter near the beginning of the exposure.
Air Sample #1	1110-1130	015/2	Syncrude	2400'	-20	N/A	-	Was exposed with Filter #1 during passes 2-20. Value opened only during plume encounter

continued ...

Table 24. Concluded.

Air Sample #2	1139-1145	015/10	Syncrude	2600'	-20	N/A	N/A	Was exposed with Filter #2 during passes 1-3, again value opened only during plume.
Air Sample #3	1216-1220	015/20	Syncrude	2600'	-19	N/A	N/A	Was exposed with Filter #3 during passes 1-3. only during plume encounter.

The aircraft was launched for a second mission to sample the Syncrude plume at a distance of 30 miles downwind, as shown in Figure 32. By this time, the winds at plume height were generally from the south-southeast, and the plume tracked along the west of the Athabasca River, and backed up against the rising terrain. Thus, while it was no longer visible, the plume was easily detected from the onboard monitors.

Table 25 presents a summary of the samples collected on this mission.

After the samples were dropped off for processing, the aircraft was returned to Calgary to complete the January field program.

6.2.5 1980 March 18

The aircraft was launched at 1540 to sample the plumes, as depicted in Figure 33. Two set of transects were conducted; the first one was 2 miles downwind of the Syncrude plant, and the second set was 2 miles downwind of the Suncor plant. Table 26 summarizes the sampling data for the two sets.

A temperature sounding conducted at 1750 showed a weak inversion at the surface, and a mixed layer through 4000' MSL, as seen in Figure 34. The hodograph from the airport showed strong veering from the surface through 6000', suggesting warm air advection in the lower altitudes. Due to the variable winds aloft, it was not possible to sample the plume at significant downwind distances.

The surface observations at the airport are shown in Table 27, and reveal good visibility and warming temperatures around 1600 hours before cooling again.

6.2.6 1980 March 19

The aircraft was launched late in the afternoon of the 1980 March 19 after being down with repairs. Once airborne, it conducted two sample transects in the Suncor plume, as shown in Figure 35. Table 28 lists the pertinent measurement data. Note that the Syncrude plume was parallel to the Suncor plume and approximatelt 500' higher.

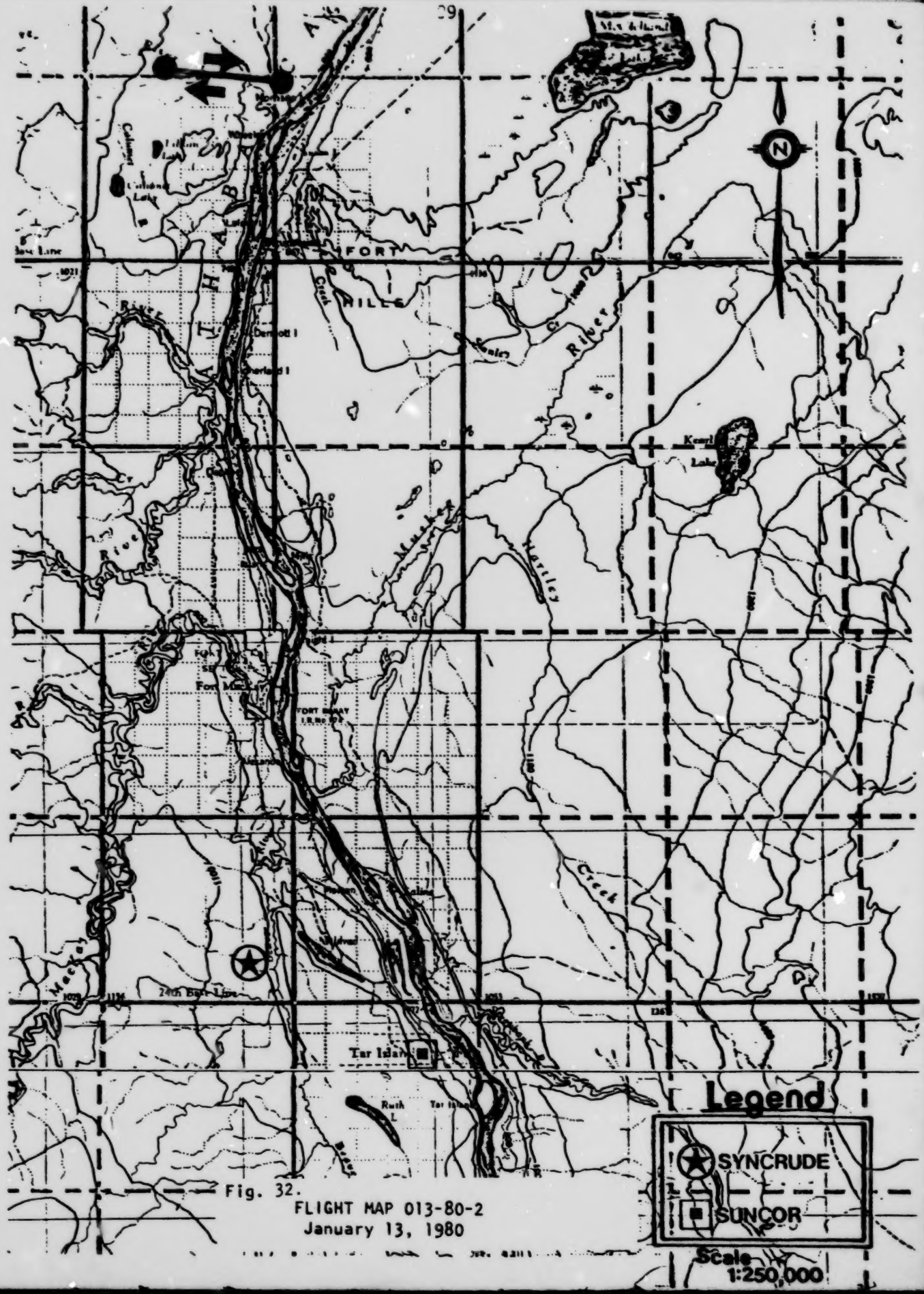


Fig. 32.
FLIGHT MAP 013-80-2
January 13, 1980

Table 25. Summary of measurements, 1980 January 13.

CASE NO. 013-80-2

Sample No.	Exposure Times	Location (Bearing from n.mi)	Source	Altitude (Feet)	Temp. (C°)	Filter Flow Rate (l/m)	Hi-Vol Flow Rates (cfm)	Remarks
Filter #1	1545-1618	360/30	Syncrude	1700'	-19	19.0-19.5	N/A	7 Transects of plume.
Air Sample #4	1555-1610	360/30	Syncrude	1700'	-19	N/A	N/A	Was exposed with Filter #1, during passes 3-5.

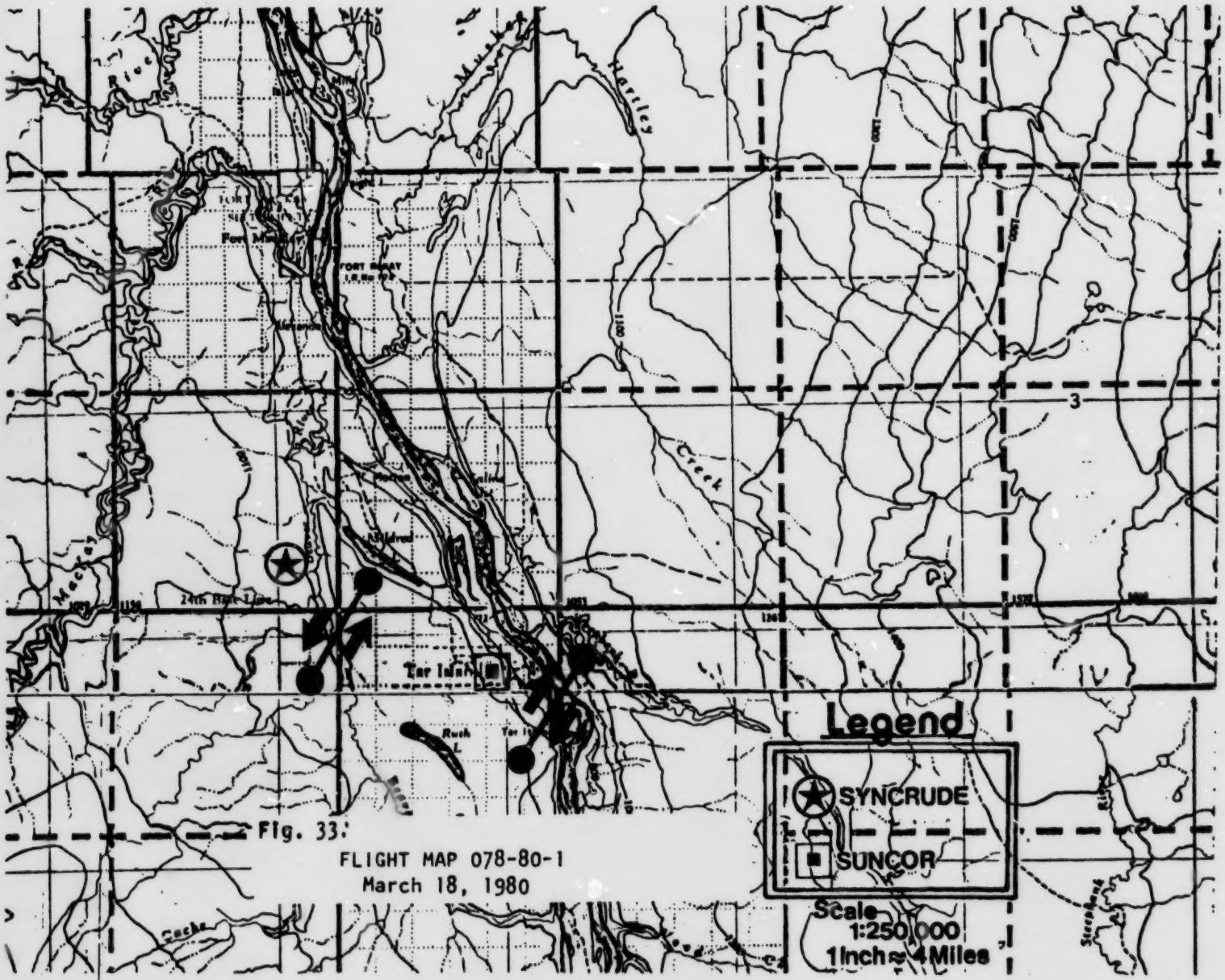


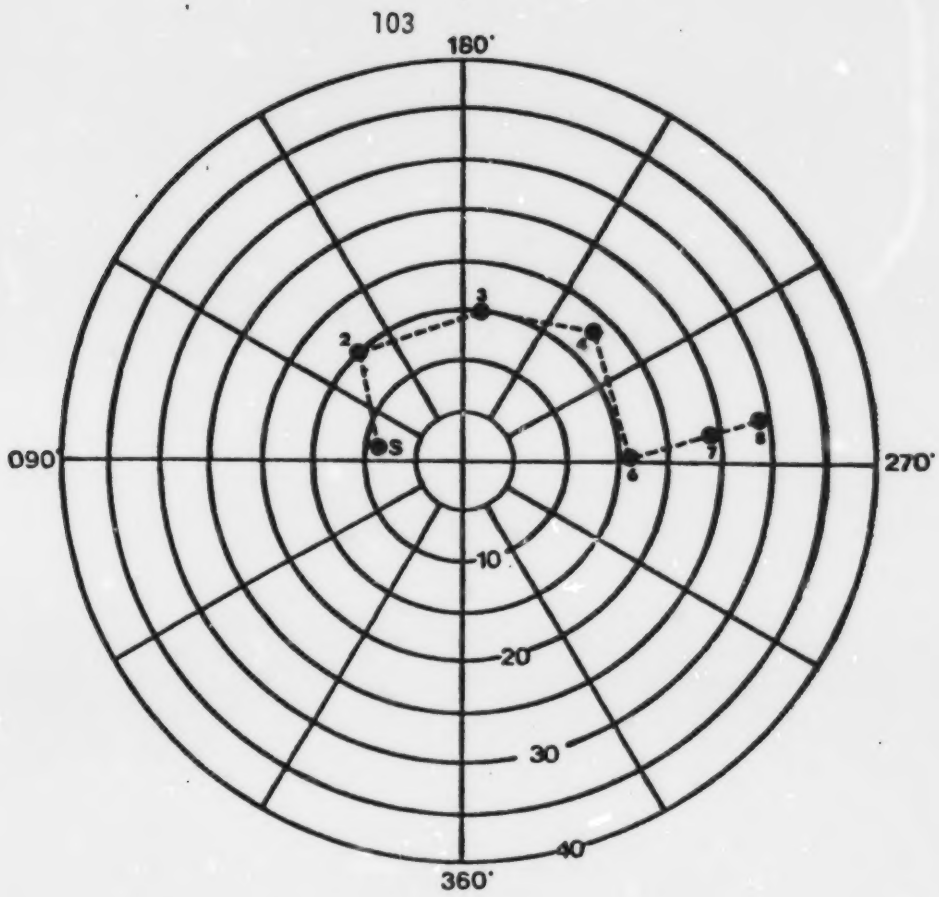
Fig. 33:

FLIGHT MAP 078-80-1
March 18, 1980

Table 26. Summary of measurements, 1980 March 18.

CASE No. 078-80-1

Sample No.	Exposure Times	Location (Bearing from n.mi)	Source	Altitude (Feet)	Temp. (C^{O})	Filter Flow Rate (l/m)	Hi-Vol Flow Rate (cfm)	Remarks
Filter #1	1545-1651	095/2	Syncrude	3200'	-3	19.0	29	
Filter #2	1702-1735	095/2	Syncrude and Suncor	3200'	-3.5	19.1	29	Believe we were mixed plumes.
Filter #3	1737-1746	180/2-15	Background	-	-	18.8	-	Background on return to Fort McMurray, flown on west side of plume.
Air Sample #1	1645-1651	095/2	Syncrude	3200'	-3	N/A	N/A	



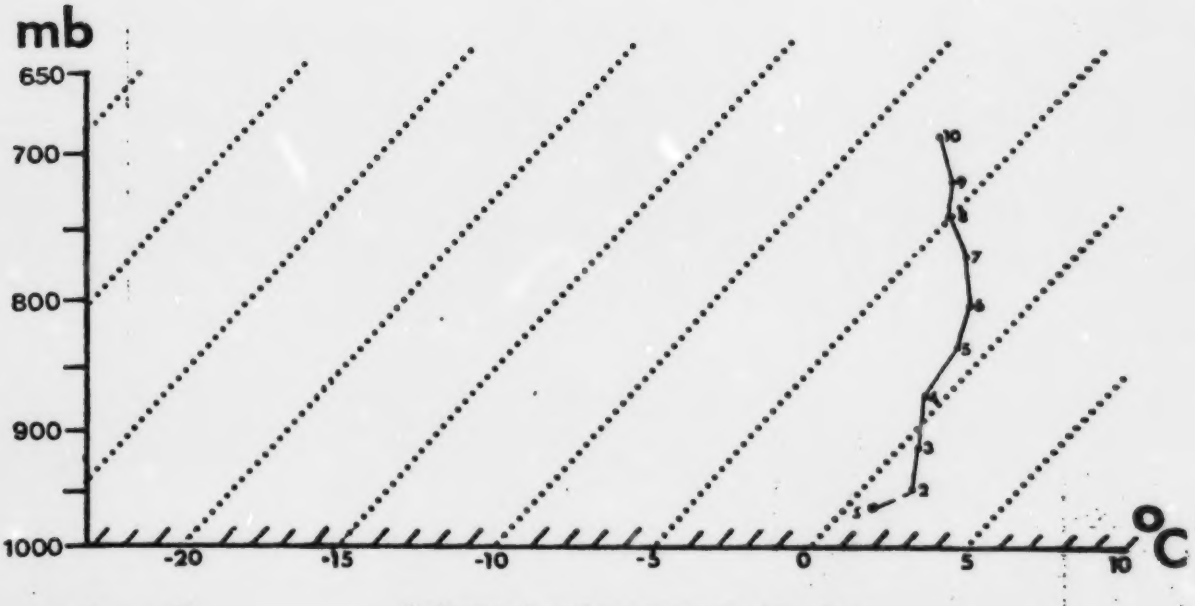


Figure 34. Hodograph & Temperature Sounding

March 18, 1980.

Sounding 1750
Hodograph 1700

Table 27. Fort McMurray surface weather observations, 1980 March 18.

TIME (MST)	TEMPERATURE (^{o}C)	DEW POINT (^{o}C)	VISIBILITY (MILES)	WIND DIRECTION (^{o}TRUE)	WIND SPEED (KTS)	PRESSURE (INCH)
1400	1	-6	15	340	02	29.48
1500	1	-6	15	310	03	29.47
1600	3	-4	15	050	03	29.47
1700	2	-5	15	040	02	29.47
1800	0	-5	15	070	05	29.47
1900	-1	-4	15	070	03	29.47

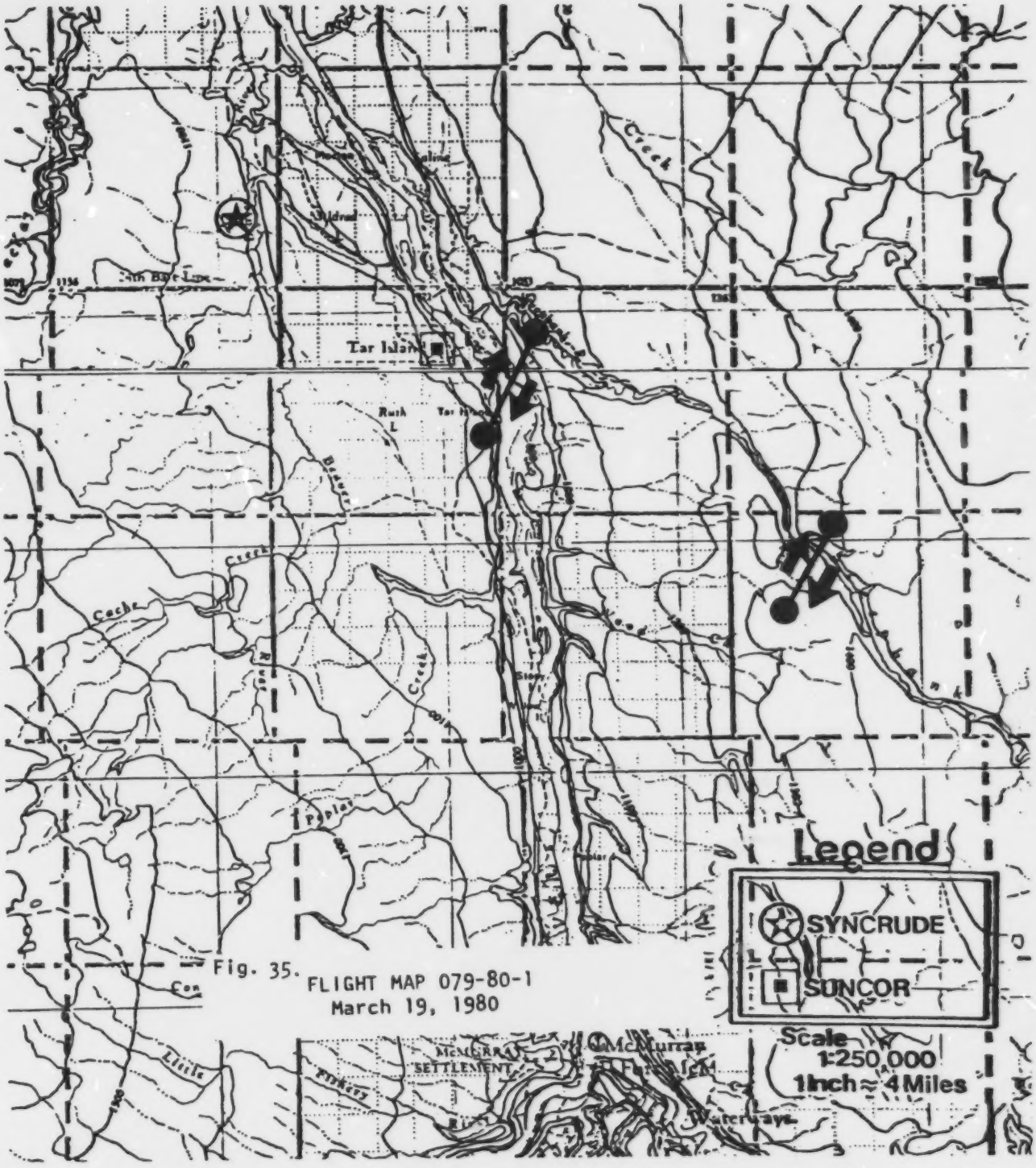


Fig. 35. FLIGHT MAP 079-80-1
March 19, 1980

Table 28. Summary of measurements, 1980 March 19.

CASE NO. 079-80-1

Sample No.	Exposure Times	Location (Bearing from n.mi)	Source	Altitude (Feet)	Temp. (C^{o})	Filter Flow Rate (l/m)	Hi-Vol Flow Rate (cfm)	Remarks
Filters #1 & #2	1728-1808	095/2	Suncor	2400'	1	15.6-16.2	N/A	
Filters #3 & #4	1820-1916	095/11	Suncor	2500'	-2	15.2	N/A	Syncrude plume parallel to this plume, approximately 500' higher.
Air Sample #1	1728-1808	095/2	Suncor	2400'		-	-	
Air Sample #2	1820-1916	095/11	Suncor	2500'	-2	-	-	

No temperature sounding was conducted on this flight. However, the winds aloft hodograph, depicted on Figure 36, suggested northwesterly winds up through the altitude of the level plume. Table 29 presents the surface observations at Fort McMurray during the late afternoon.

6.2.7 1980 March 20

The case study on March 20 provided a good comparison between the two plumes, in that both were flown 2 miles downwind from the respective stacks, as shown in Figure 37. Furthermore, a background exposure 20 miles upwind of Syncrude was also conducted.

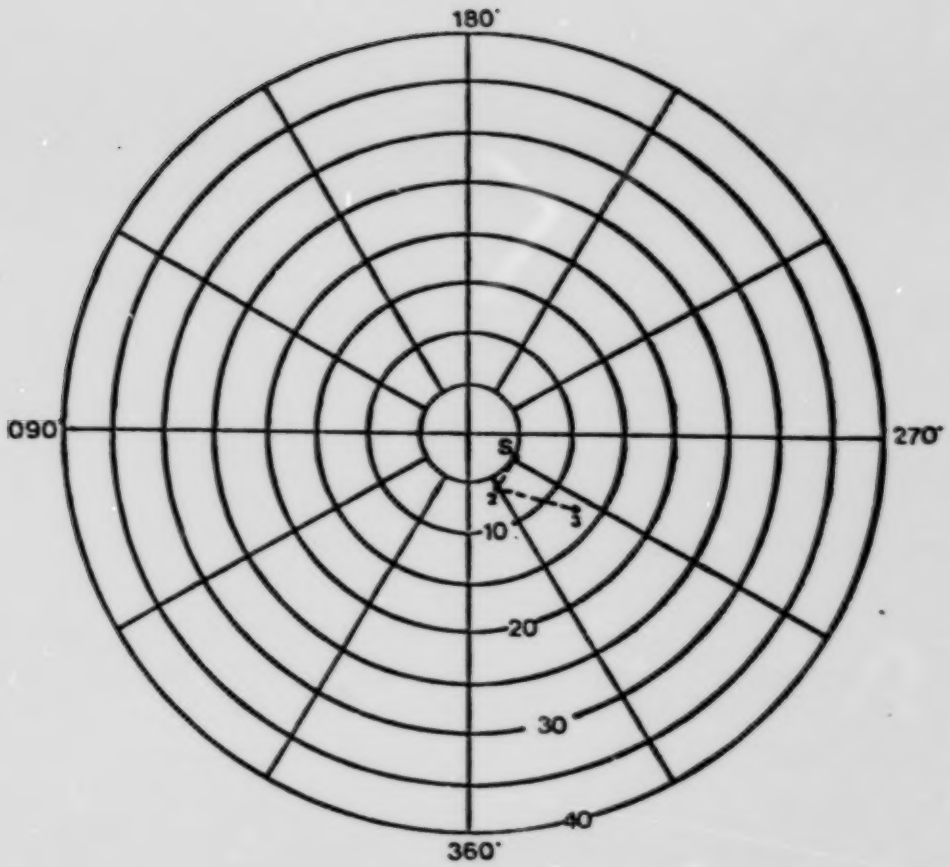
Table 30 lists the measurements conducted on this case. Note the remarks of a trapping inversion at 3400', which is consistent with the aircraft sounding depicted in Figure 38. The hodograph, on the same figure, shows very light southerly winds below the inversion, and stronger north-westerly winds above. Table 31 presents the surface weather observations for this area. Note the good visibility along with the report of very light snow in the early hours.

6.2.8 1980 March 21

Two flights were conducted on ths day; the first is depicted in Figure 39, in which the aircraft sampled the Syncrude plume. The winds were light throughout the lower levels, as seen on the hodograph of Figure 40. While the hodograph winds suggest a westerly flow, in fact the plume tracked to the south of the plants. Table 32 lists the measurement samples for this case. Note the possibility of plume mixture during the second set of filter exposures.

Table 33 lists the surface weather conditions during the day. Before 1400 hours the winds were light and northerly, coupled with light snow. After that period the sky conditions improved, and the winds shifted to the west. The second set of transects was made during this wind transition.

After returning to the airport, the aircraft was launched for a second mission, shown in Figure 41. A series of transects was flown over the Athabasca River approximately 5 miles north of the city. At



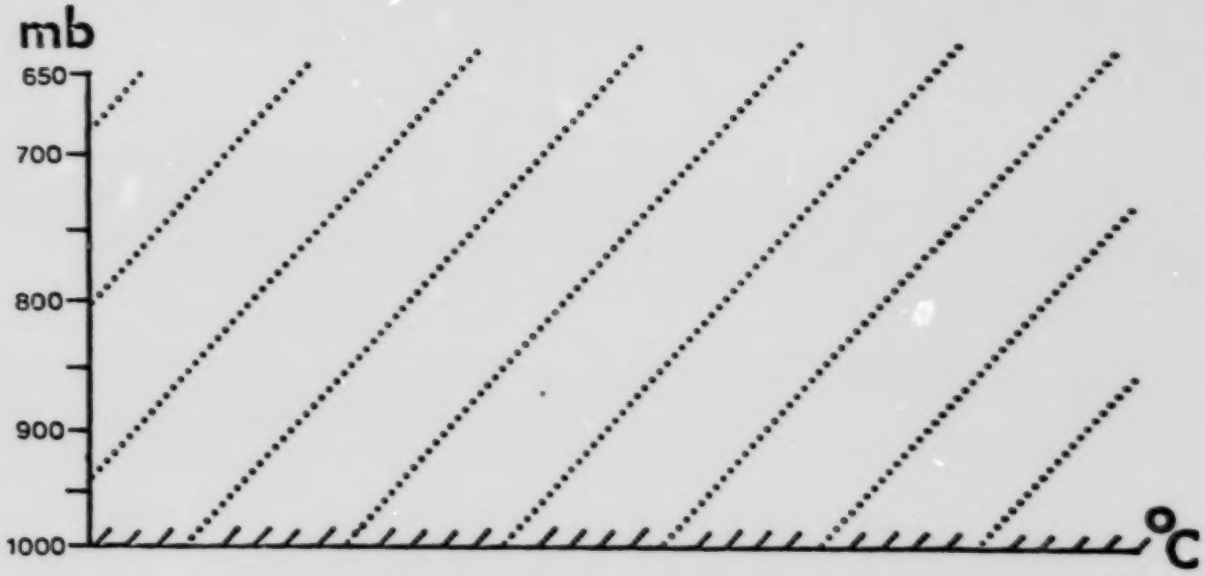


Figure 36. Hodograph

March 19, 1980. 1700 hrs.

Table 29. Fort McMurray surface weather observations, 1980 March 19.

TIME (MST)	TEMPERATURE (^{o}C)	DEW POINT (^{o}C)	VISIBILITY (MILES)	WIND DIRECTION (^{o}TRUE)	WIND SPEED (KTS)	PRESSURE (INCH)
1600	1	-5	15	290	06	29.83
1700	1	-7	15	240	05	29.84
1800	0	-8	15	190	03	29.85
1900	-2	-7	15	180	05	29.86
2000	-4	-9	15	190	05	29.89
2100	-3	-8	15	190	03	29.90

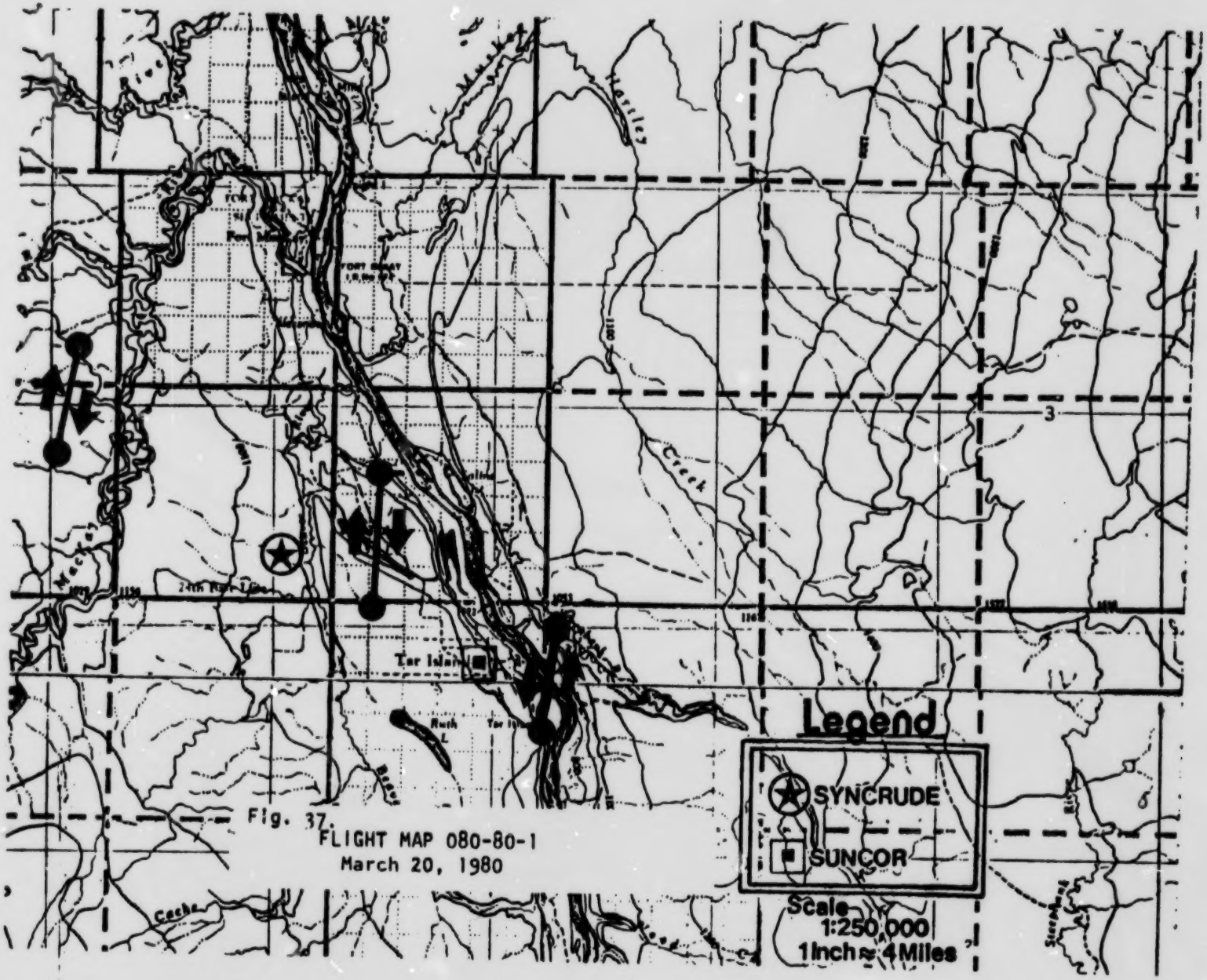
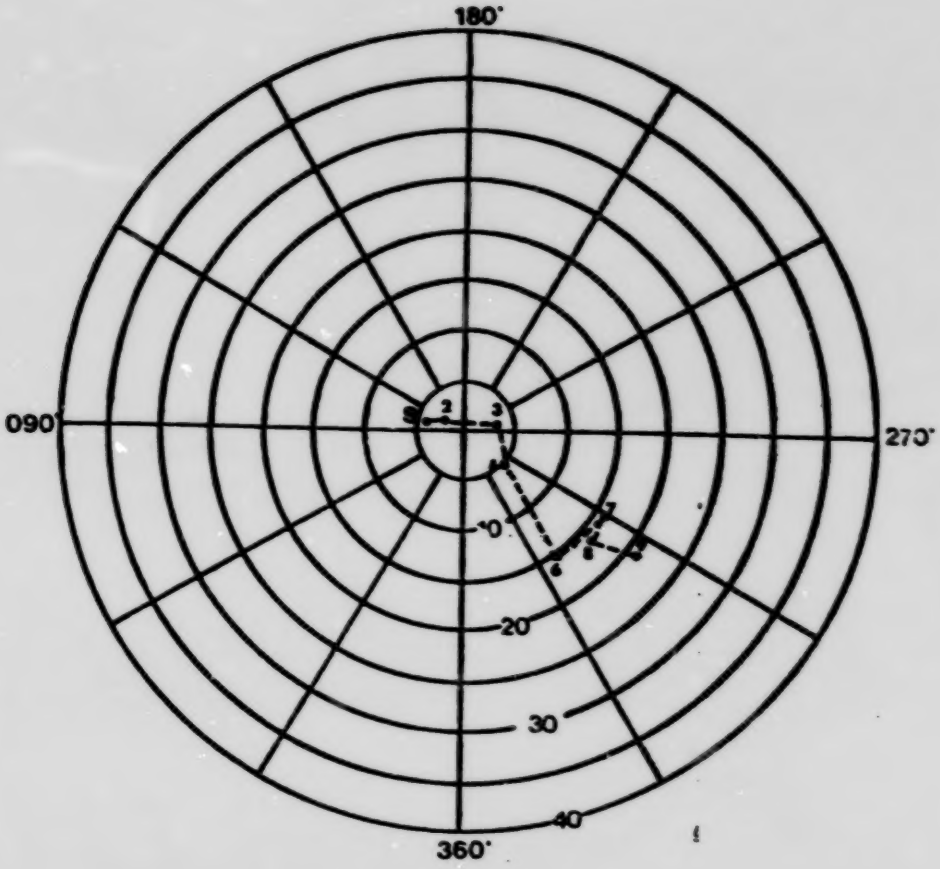


Fig. 37.
FLIGHT MAP 080-80-1
March 20, 1980

Table 30. Summary of measurements, 1980 March 20.

CASE NO. 080-80-1

Sample No.	Exposure Times	Location (Bearing from n.mi)	Source	Altitude (Feet)	Temp. (C^{o})	Filter Flow Rate (l/m)	Hi-Vol Flow Rate (cfm)	Remarks
Filter #2	1032-1104	290/20	Background	3000'	-7.5	14.8	29	Secondary filter pack.
Filters #1 & #2	1112-1230	090/2	Syncrude	3300'	-6.5	15.0	-	Trapping inversion 3400'.
Filters #3 & #4	1238-1410	090/2	Suncor	3300'	-6.5	14.6	-	Possible mixture of both plumes.
Air Sample #1	1032-1104	290/20	Background	3000'	-7.5	-	-	
Air Sample #2	1112-1230	090/2	Syncrude	3300'	-6.5	-	-	
Air Sample #3	1238-1410	090/2	Suncor	3300'	-6.5	-	-	



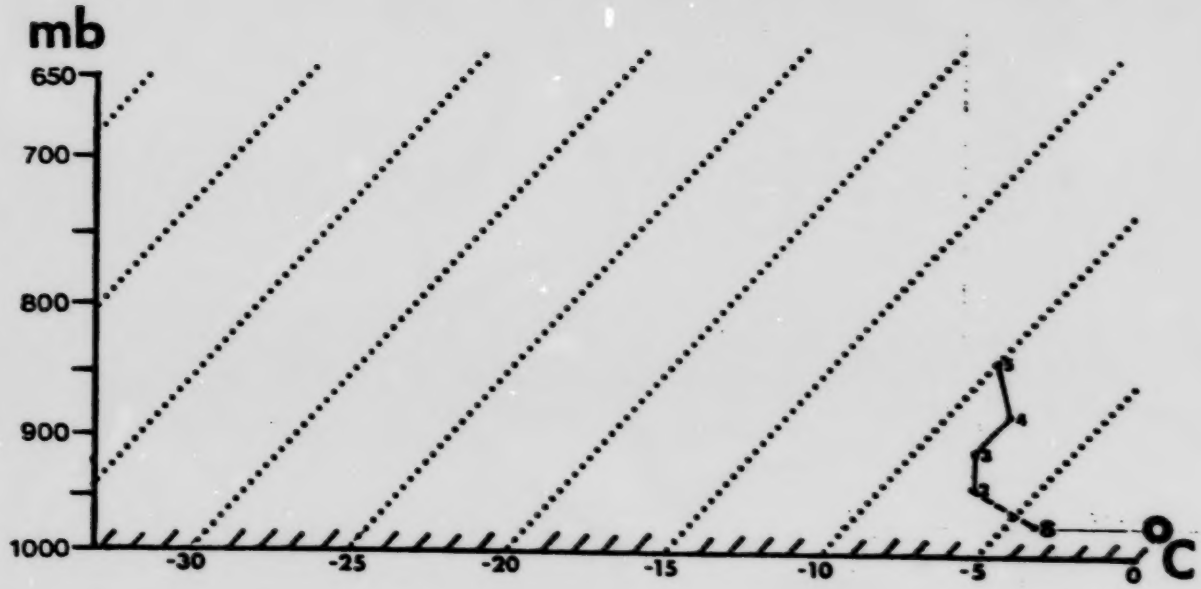


Figure 38. Hodograph & Temperature Sounding
March 20, 1980

Sounding 1015
Hodograph 1100

Table 31. Fort McMurray surface weather observations, 1980 March 20.

TIME (MST)	TEMPERATURE (^{o}C)	DEW POINT (^{o}C)	VISIBILITY (MILES)	WIND DIRECTION (^{o}TRUE)	WIND SPEED (KTS)	PRESSURE (INCH)
0800	-8	-10	15s--	180	03	30.03
0900	-6	-9	15	00	00	30.05
1000	-3	-8	15	070	03	30.05
1100	-2	-8	15	350	03	30.05
1200	-1	-7	15	00	00	30.05
1300	0	-5	15	00	00	30.06
1400	0	-6	15	00	04	30.04
1500	1	-6	15	310	04	30.04
1600	0	-7	15	310	04	30.05

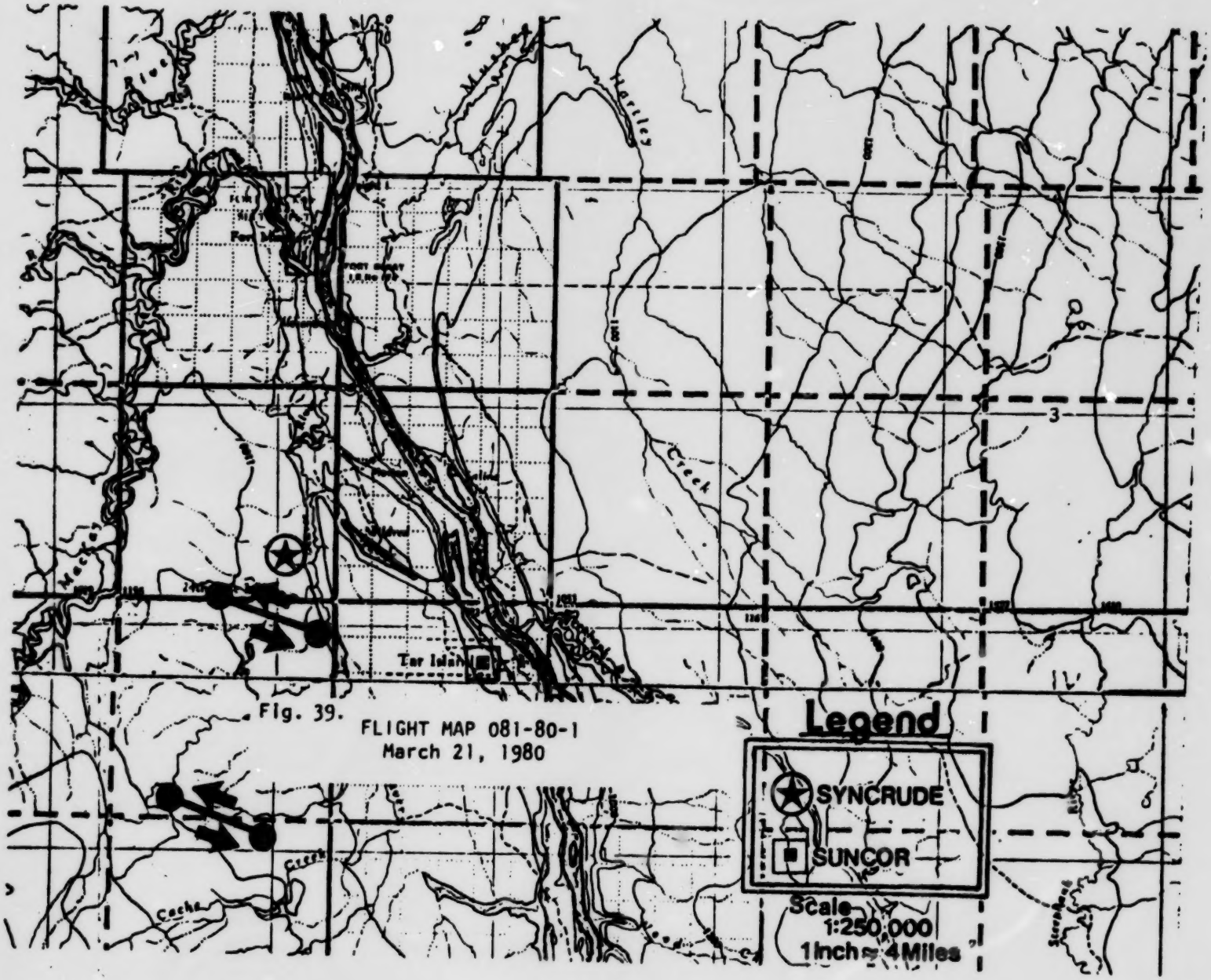
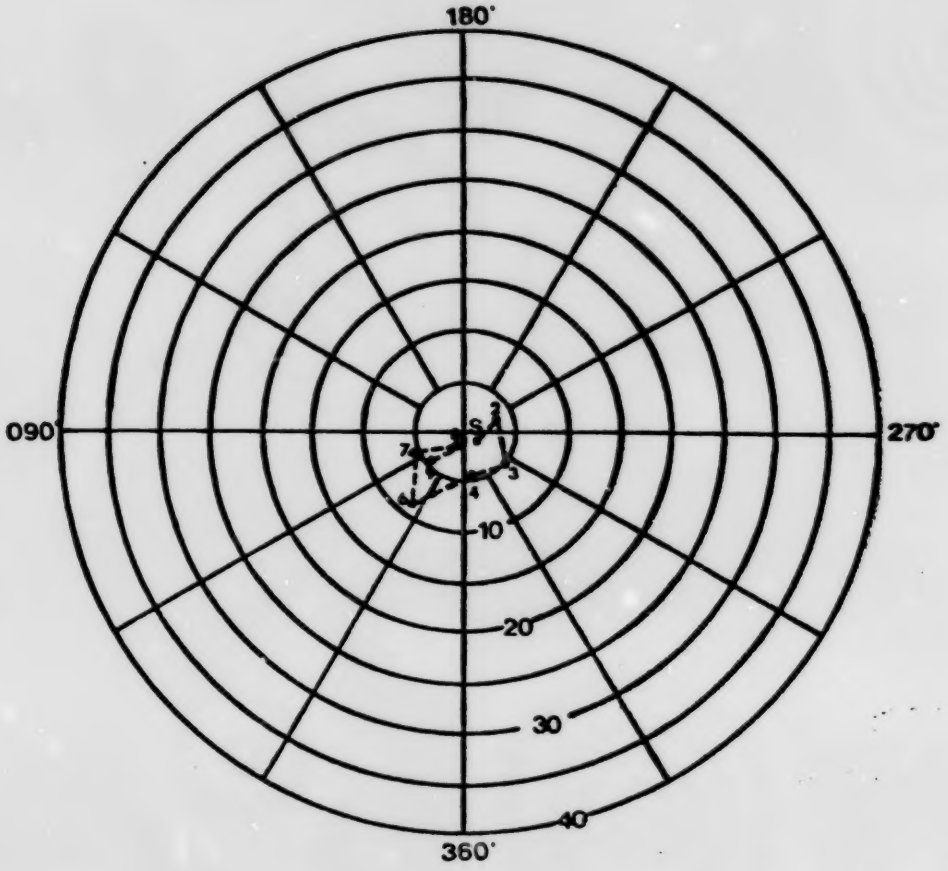


Fig. 39. FLIGHT MAP 081-80-1
March 21, 1980



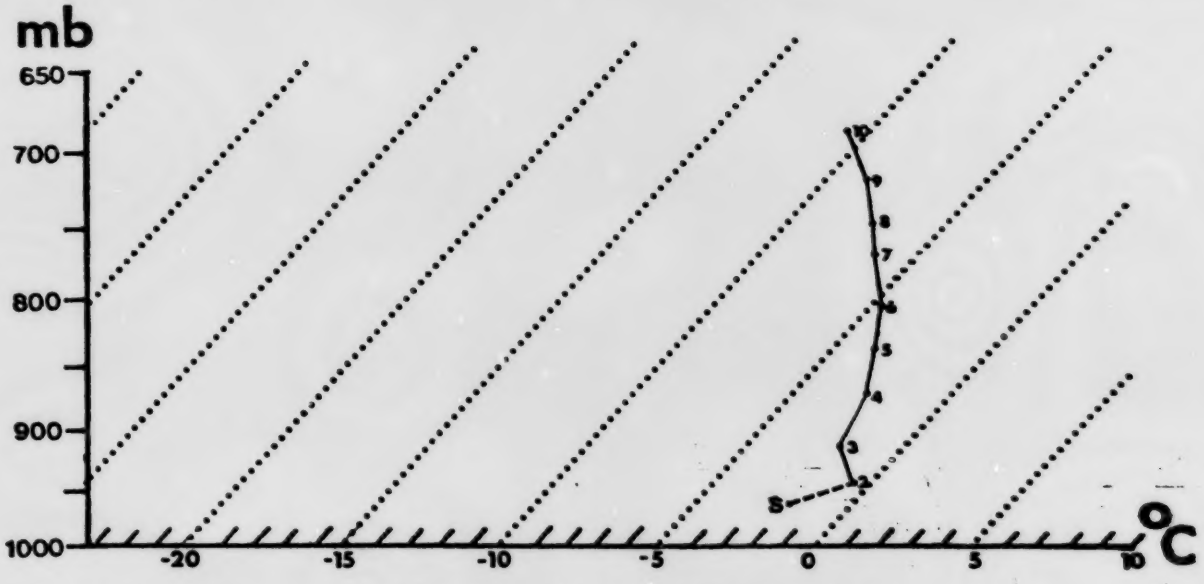


Figure 40. Hodograph & Temperature Sounding

March 21, 1980

Sounding 1600 hrs.
Hodograph 1700 hrs.

Table 32. Summary of measurements, 1980 March 21.

CASE NO. 081-80-1

Sample No.	Exposure Times	Location (Bearing from n.mi)	Source	Altitude (Feet)	Temp. (C^0)	Filter Flow Rate (l/m)	Hi-Vol Flow Rate (cfm)	Remarks
Filters #1 & #2	1225-1351	200/2	Syncrude	2400'	-4.5	15.1	N/A	
Filters #3 & #4	1402-1531	200/8	Syncrude	2400'	-4.5	14.9	N/A	This set of filters could have a mixture of both plumes.
Air Sample #1	1225-1351	200/2	Syncrude	2400'	-4.5	N/A	N/A	
Air Sample #2	1402-1531	200/8	Syncrude	2400'	-4.5	N/A	N/A	

Table 33. Fort McMurray surface weather observations, 1980 March 21.

TIME (MST)	TEMPERATURE (^{o}C)	DEW POINT (^{o}C)	VISIBILITY (MILES)	WIND DIRECTION (^{o}TRUE)	WIND SPEED (KTS)	PRESSURE (INCH)
1000	-8	-9	1.5s--	010	02	30.10
1100	-7	-9	1.5s--	040	03	30.08
1200	-4	-8	3 s--	020	05	30.10
1300	-4	-8	4 s--	270	05	30.09
1400	-2	-7	10	310	06	30.09
1500	-3	-7	15	270	07	30.10
1600	-2	-7	15	240	04	30.07
1700	-2	-7	15	260	07	30.08

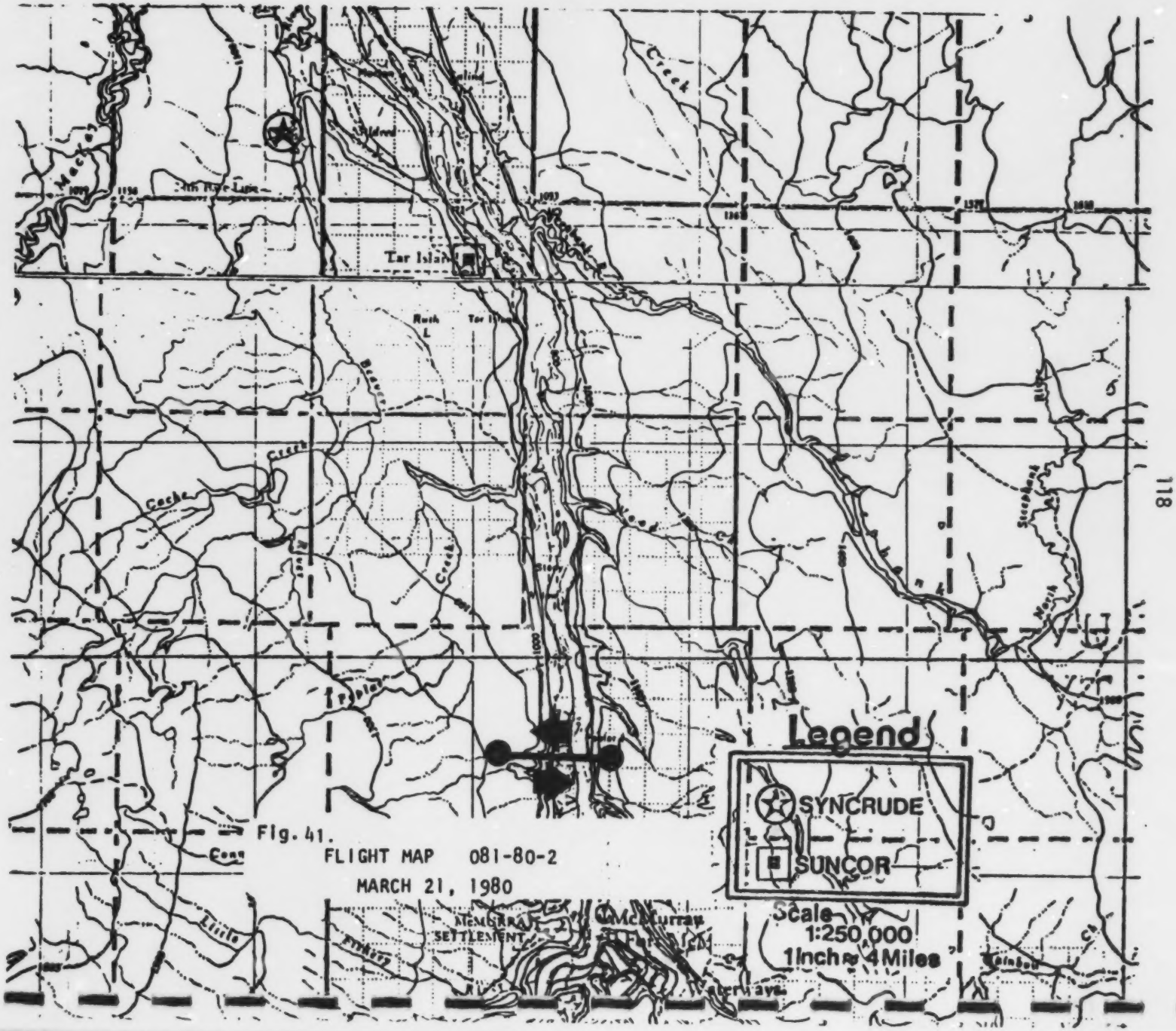


Fig. 41.
FLIGHT MAP 081-80-2
MARCH 21, 1980

that time the plumes appeared to be tracking along the river and had appeared to have merged with each other. Table 34 summarizes the batch measurements for this case.

6.2.9 1980 March 24

The aircraft flew one mission on this day, as shown in Figure 42. The first set of measurements was a background sample conducted near Bitumount, as the winds were from the north. Figure 43 shows that the winds throughout the lower levels were 10 to 20 kts from the north.

After the background run the aircraft conducted a series of stacked traverses just downwind of the Syncrude plant, in order to determine the plume structure in more detail. Table 35 lists the altitudes that were flown during this series.

After completion of the Syncrude sampling, the aircraft set up a series of runs through the Suncor plume. It was evident that the two plumes were not mixing at this distance downwind of the stacks. This, too, should provide a useful comparison between the plumes.

6.2.10 1980 March 25

There were two cases flown in this last day of the March series. The first, as shown in Figure 44, was conducted at several altitudes overhead the Syncrude plant, as well as 25 miles to the north. Table 37 describes the location of these special air bag sample flights. Upon completion of this series, the aircraft conducted a set of transects 2 miles south of the Syncrude plant. The hodograph for this morning, Figure 45, showed northerly winds through the depth of the plume.

Table 38 lists the surface weather observations for this day. Note the steadily increasing temperatures throughout the day. During the morning the plume was beneath an inversion around 4000' MSL. During the afternoon, hwever, the winds shifted to the west, and the lower layers of the atmosphere became well mixed. This is seen in the aircraft sounding on Figure 46.

Table 34. Summary of measurements, 1980 March 21.

CASE NO. 081-80-2

Sample No.	Exposure Times	Location (Bearing from n.mi)	Source	Altitude (Feet)	Temp. (C^{o})	Filter Flow Rate (l/m)	Hi-Vol Flow Rate (cfm)	Remarks
Filters #1 & #2	1715-1849	170/20	Syncrude and Suncor	3000'	-	-	-	Filters exposed the secondary filter pack.
Air Samples	1715-1849	170/20	Syncrude and Suncor	3000'	-	-	-	

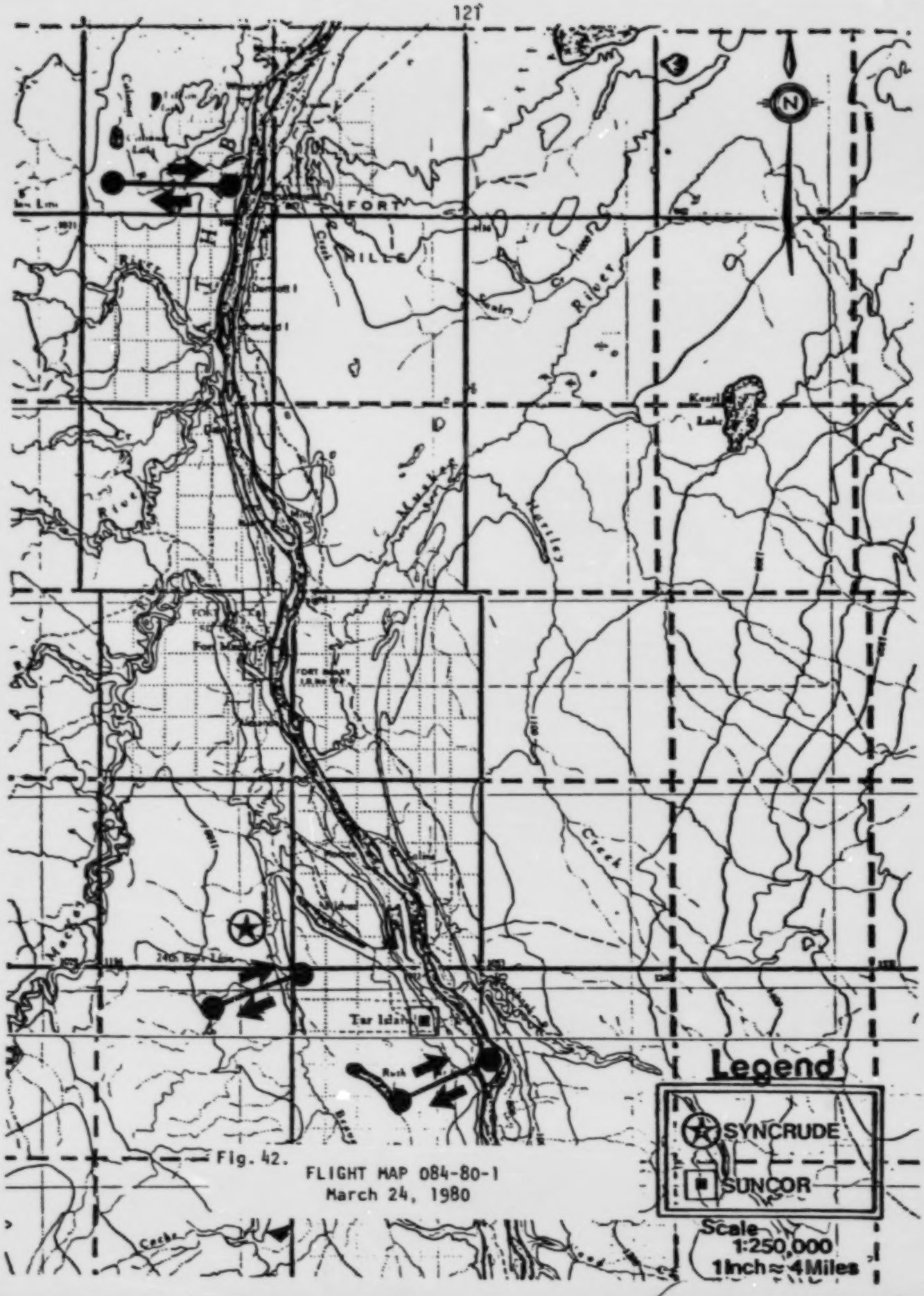
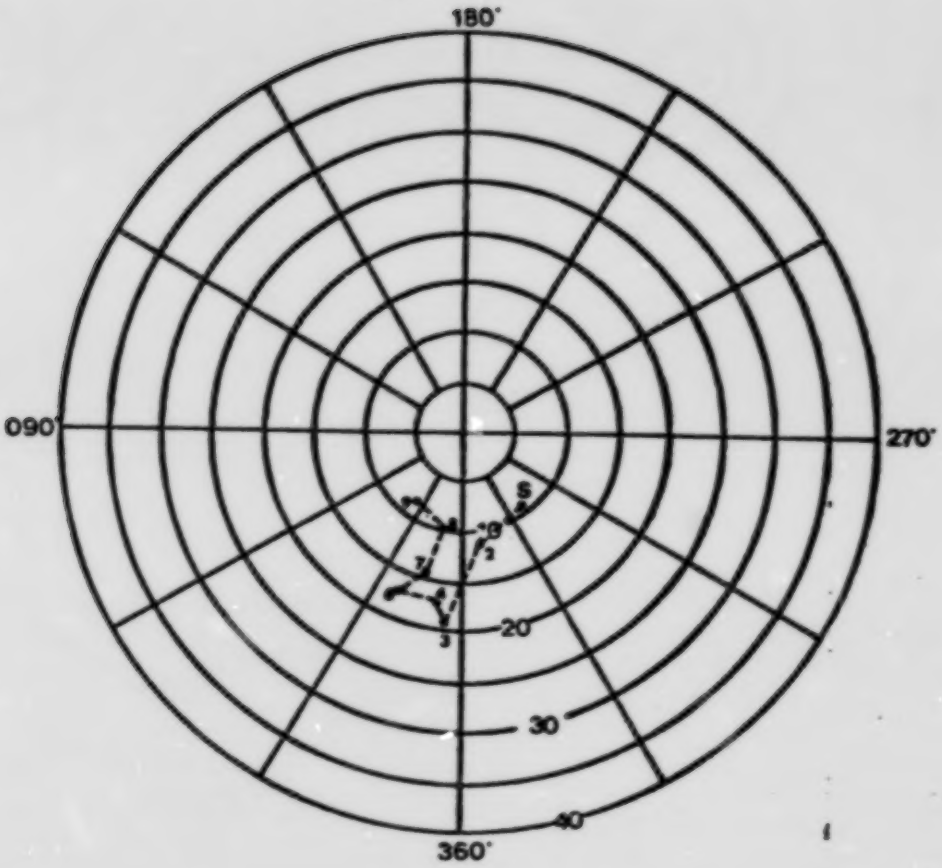


Fig. 42. FLIGHT MAP 084-80-1
March 24, 1980



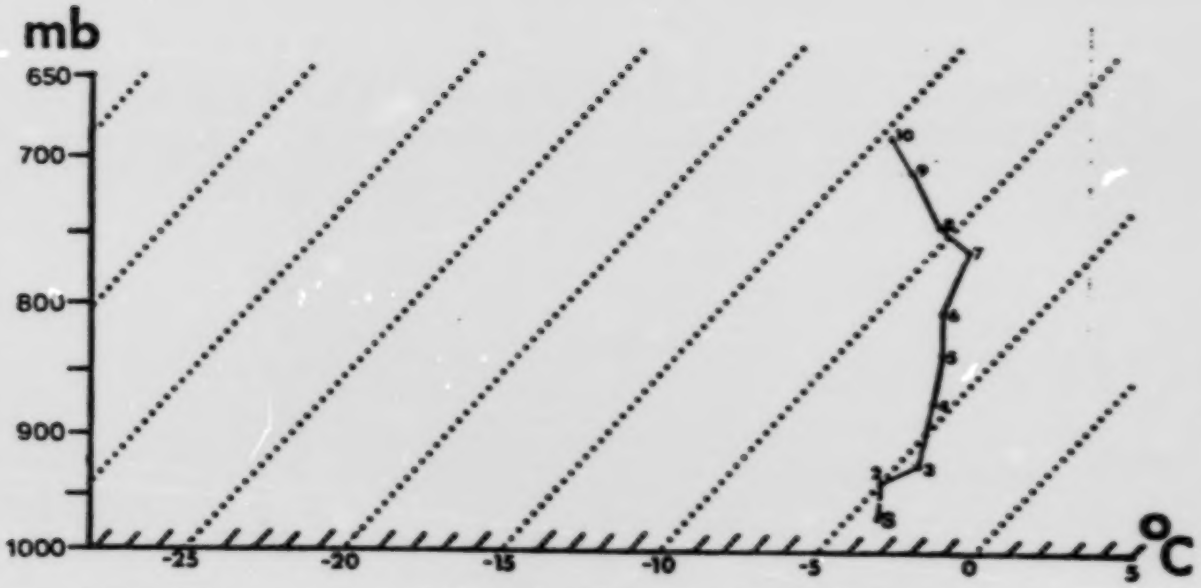


Figure 43. Hodograph & Temperature Sounding

March 24, 1980

Sounding 0915
Hodograph 1100

Table 35. Summary of measurements, 1980 March 24.

CASE NO. 084-80-1

Sample No.	Exposure Times	Location (Bearing from n/mi)	Source	Altitude (Feet)	Filter Flow Rate (l/m)	Hi-Vol Flow Rate (cfm)	Remarks
Filter #1	0936-1008	360/25	Background	3500'	15.0	29	Used secondary filter pack. Also exposed hi-vol filter
Filters #1 & #2	1013-1130	170/2	Syncrude	2500' to 2900'	-	-	Varied altitudes for profile: Pass #1 3300' Pass #2 3100' Pass #3 2900' Pass #4 2700' Pass #5 2500'
Filters #3 & #4	1135-1315	170/2	Suncor	3100'	-	-	Exposed hi-vol filter
Air Samples #1	0936-1008	360/25	Background	3500'	-	-	
Air Samples #2	1135-1315	170/2	Suncor	3100'	-	-	

Table 36. Fort McMurray surface weather observations, 1980 March 24.

TIME (MST)	TEMPERATURE (^{o}C)	DEW POINT (^{o}C)	VISIBILITY (MILES)	WIND DIRECTION (^{o}TRUE)	WIND SPEED (KTS)	PRESSURE (INCH)
0700	-5	-7	15	310	08	30.09
0800	-4	-8	15	310	07	30.09
0900	-4	-8	15	310	07	30.09
1000	-4	-9	15	310	08	30.09
1100	-1	-7	15	300	11	30.08
1200	-1	-8	15	300	13	30.08
1300	0	-7	15	320	11	30.07
1400	1	-5	15	330	13	30.07
1500	1	-4	15	360	10	30.06

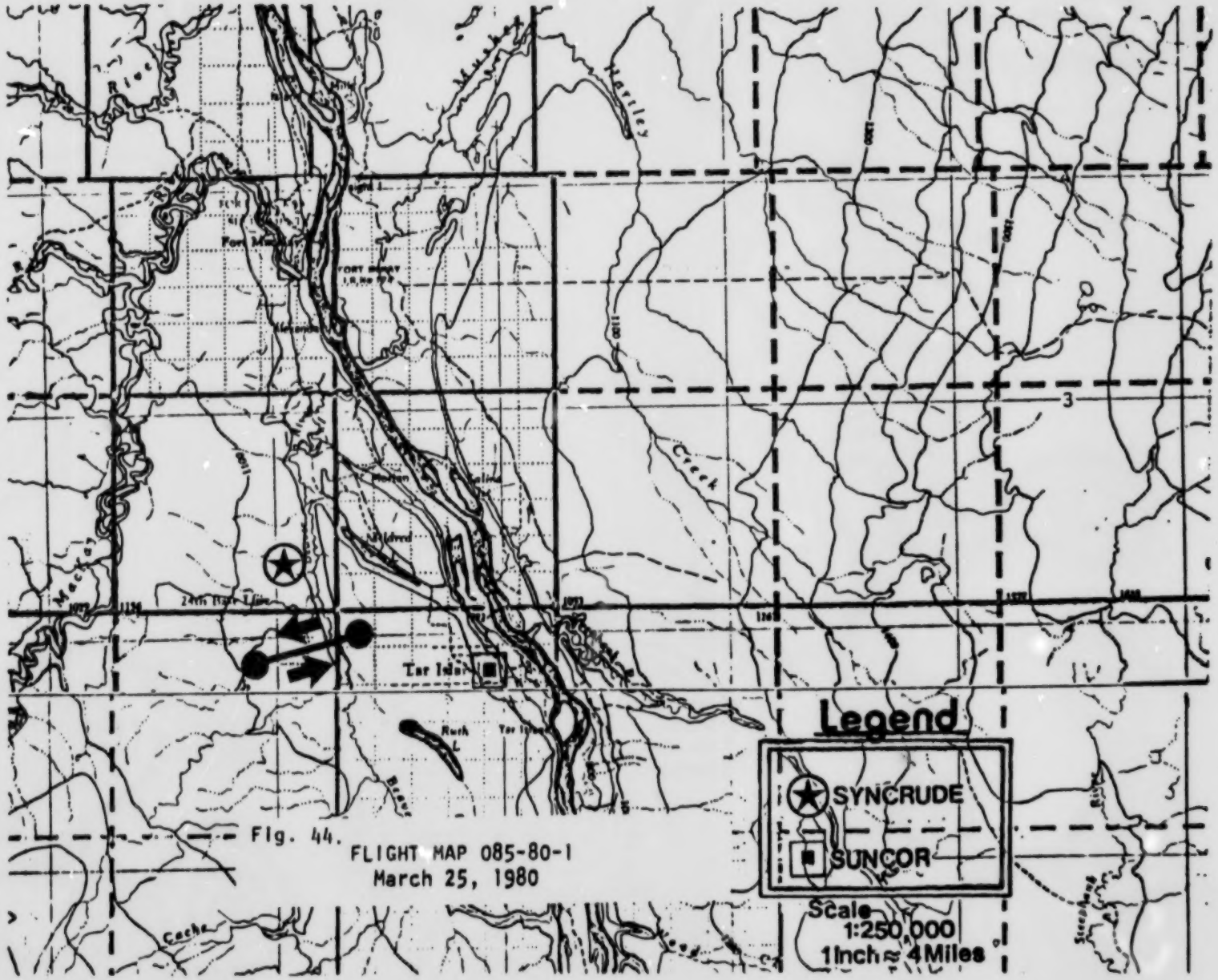


Fig. 44. FLIGHT MAP 085-80-1
March 25, 1980

Table 37. Summary of measurements, 1980 March 25.

CASE NO. 085-80-1

Sample No.	Exposure Times	Location (Bearing from mi)	Source	Altitude (Feet)	Temp. (C^{o})	Filter Flow Rate (l/m)	Hi-Vol Flow Rate (cfm)	Remarks
Filters #2 & #2	1010-1110	170/2	Syncrude	4000'	-	13/8	29	Varied altitudes for profile. Pass #1 4500' Pass #2 4300' Pass #3 4100' Pass #4 3900' Pass #5 3700' Pass #6 3500' Inversion broke up by 1030. Also exposed hi-vol filter.
Air Sample B-1	-		Directly over Syncrude	8000'	-	-	-	
Air Sample B-2		360/25	Background	8000'	-	-	-	
Air Sample B-3		360/25	Background	3000'	-	-	-	

continued ...

Table 37. Concluded.

Air Sample B-4			Directly over Syncrude open pit	1300'	-	-	-
Air Sample #1	1010-1110	170/2	Syncrude	4000'	-	-	-

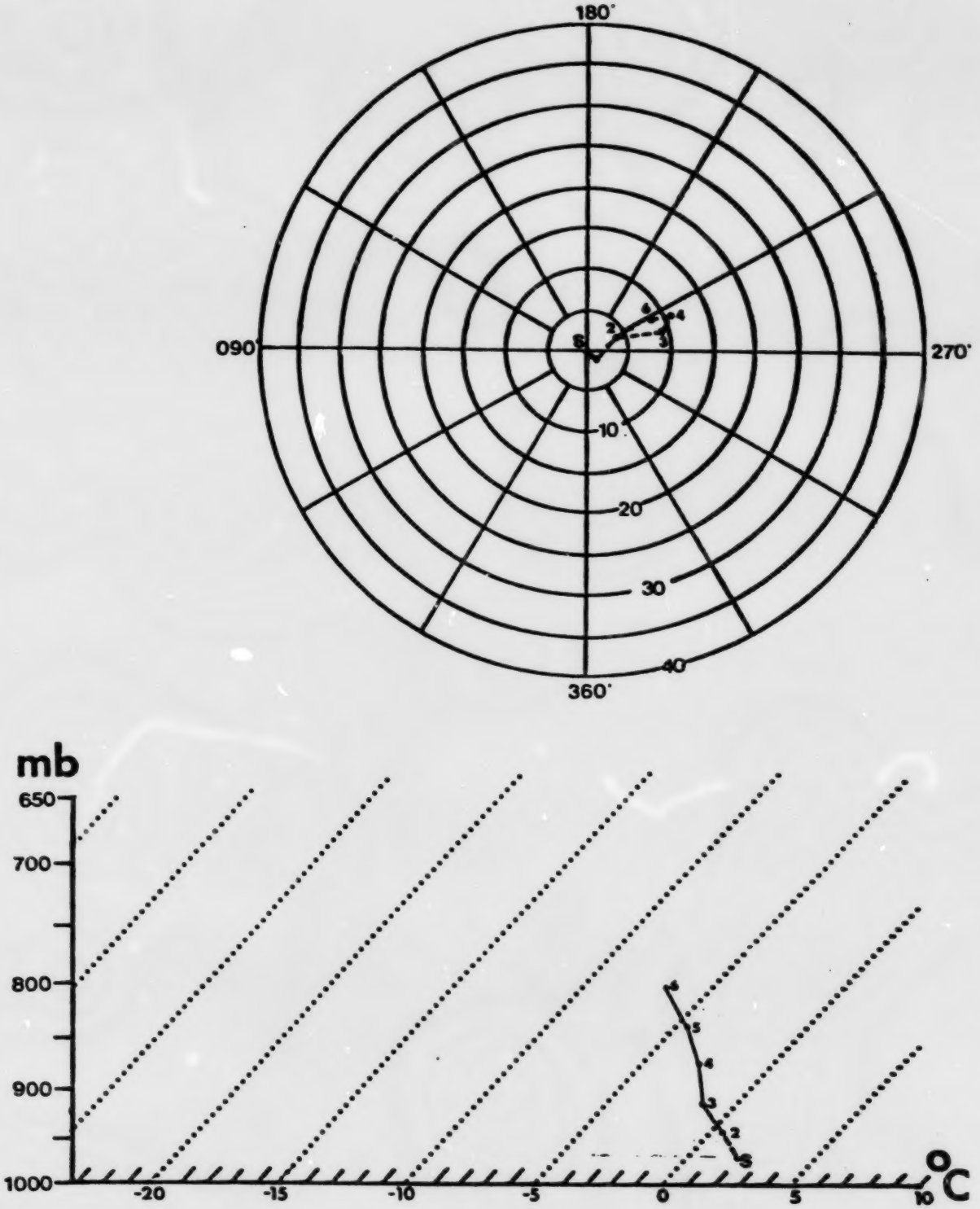


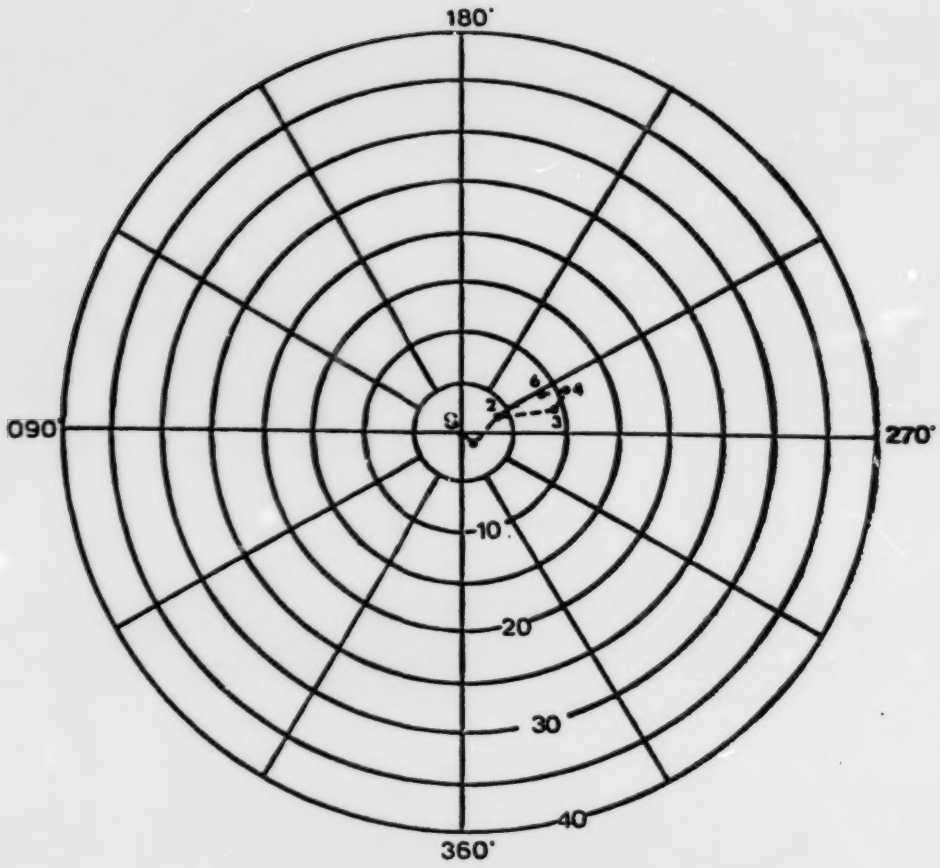
Figure 45. Hodograph & Temperature Sounding

March 25, 1980

Sounding 1630
Hodograph 1700

Table 38. Fort McMurray surface weather observations, 1980 March 25.

TIME (MST)	TEMPERATURE (^{o}C)	DEW POINT (^{o}C)	VISIBILITY (MILES)	WIND DIRECTION (^{o}TRUE)	WIND SPEED (KTS)	PRESSURE (INCH)
0700	-12	-13	15	210	07	30.13
0800	-10	-11	15	210	04	30.13
0900	-7	-10	15	250	03	30.13
1000	-4	-10	15	250	04	30.12
1100	-2	-9	15	240	03	30.11
1200	-1	-7	15	250	04	30.09
1300	2	-9	15	240	04	30.07
1400	2	-7	15	230	02	30.06
1500	2	-5	15	300	02	30.04
1600	2	-4	15	00	00	30.03
1700	3	-6	15	00	00	30.02



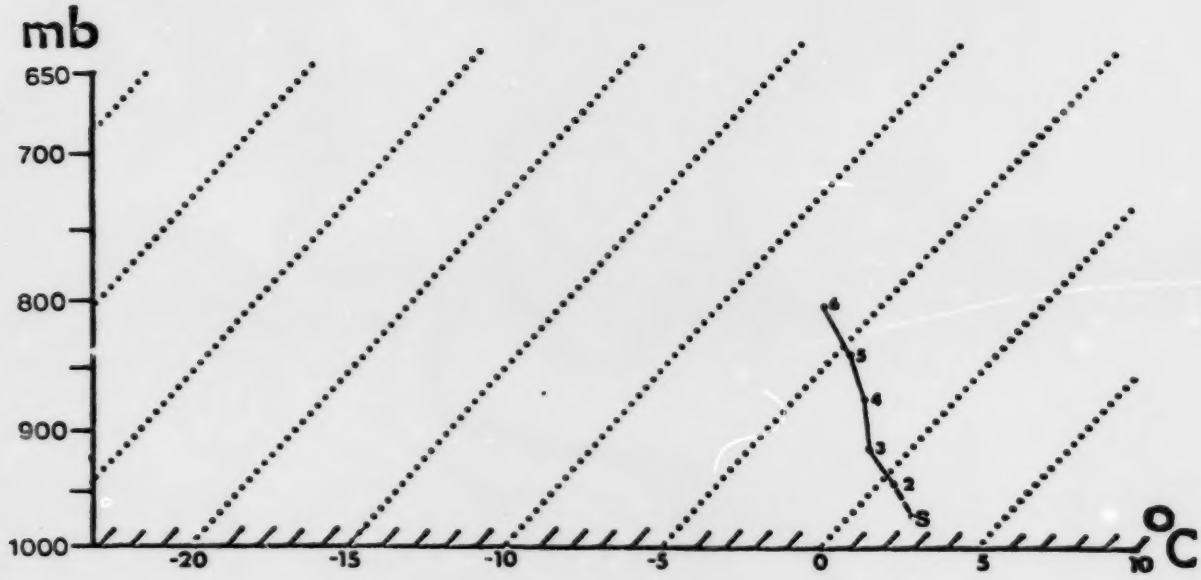


Figure 46. Hodograph & Temperature Sounding

March 25, 1980

Sounding 1630
Hodograph 1700

The afternoon flight, Figure 47, was the only case study that sampled the plumes in a neutral boundary layer. There was some evidence of plume fumigation during the early afternoon.

After the filters and air bags were dropped off, the aircraft returned to Calgary to terminate the March field program.

6.2.11 1980 June 25, 2035-2305

The aircraft arrived in the Alberta Oil Sands area on 1980 June 25, to conduct the field program. The first mission was also flown on the 25th to test the gas analyzers and batch samplers. The aircraft was launched at 2035 MDT to conduct a temperature-dew point temperature sounding, followed by a plume sampling run. However, the SO_2 monitor did not function properly, and the mission was subsequently terminated.

One sample bag was filled during the plume traverses at a distance of approximately 1 mile from the Syncruce plant, as shown in Figure 48. This sample was taken at an altitude of 2500 ft. (ASL). See Table 4 for this flight summary.

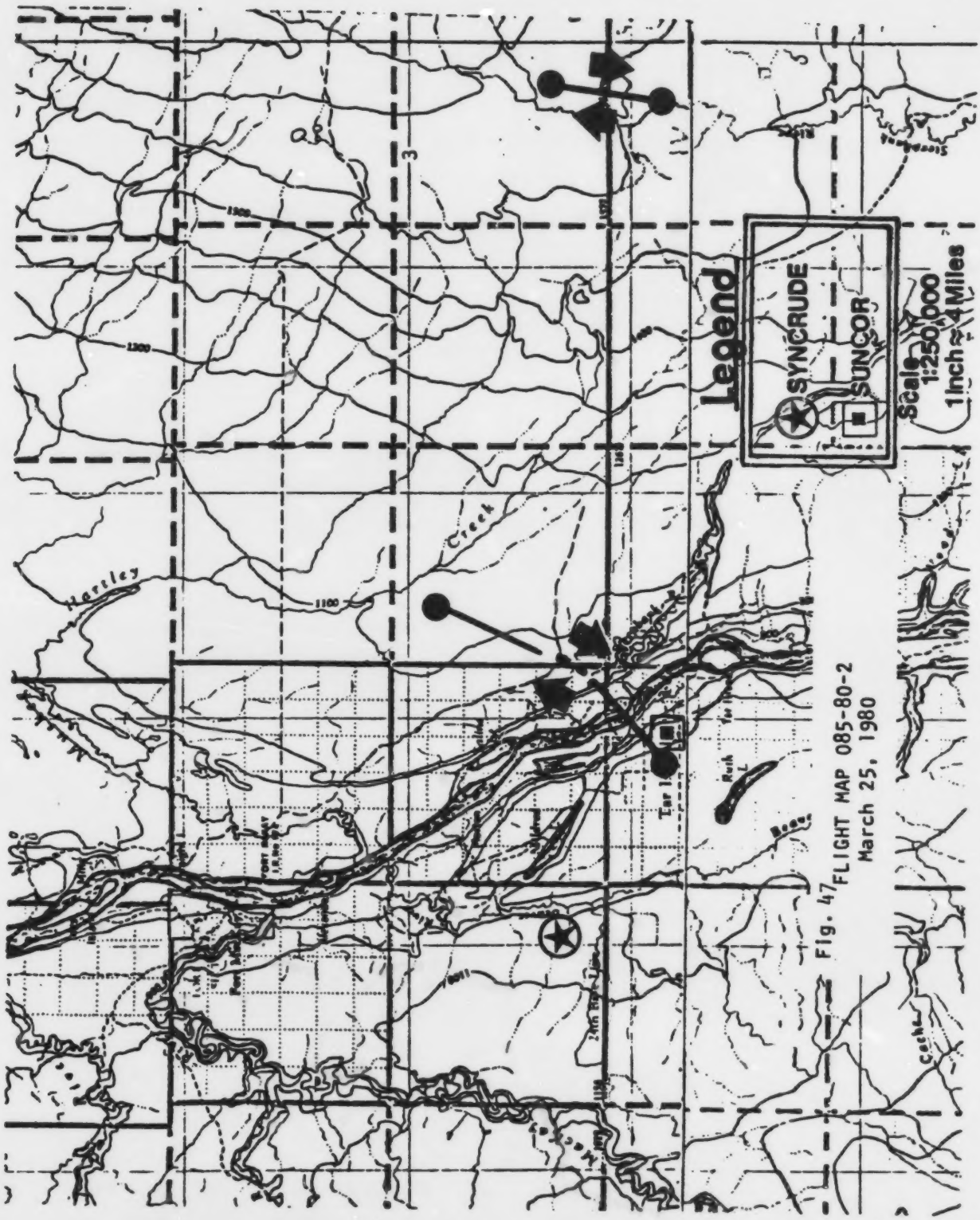
6.2.12 1980 June 28, 1230-1540

The aircraft was launched at 1230 to sample the plumes. Several transects were conducted, along with one background run to the west of the plants, as shown in Figure 49. However, the SO_2 monitor continued to function improperly, and the flight was terminated. Table 41 summarizes the batch samples collected in this flight.

After this flight it was decided that any further flights without a reliable SO_2 monitor would not be satisfactory. Several efforts were made to remedy the situation, including locating an alternate system, and ordering repair parts for the original unit, before the data sampling could be resumed on 04 July.

6.2.13 1980 July 04, 1000-1350

The flight on 04 July was characterized by light westerly winds at the Fort McMurray airport, as shown in Table 42. The sky cover was scattered clouds throughout the late morning, and, by late morning, the boundary layer up to cloud base was well-mixed. Figure 50 depicts


Legend
SYNCRUDE
SUNCOR
Scale
1:250,000
1 Inch ≈ 4 Miles
Creek
Fig. 47 FLIGHT MAP 085-80-2
March 25, 1980

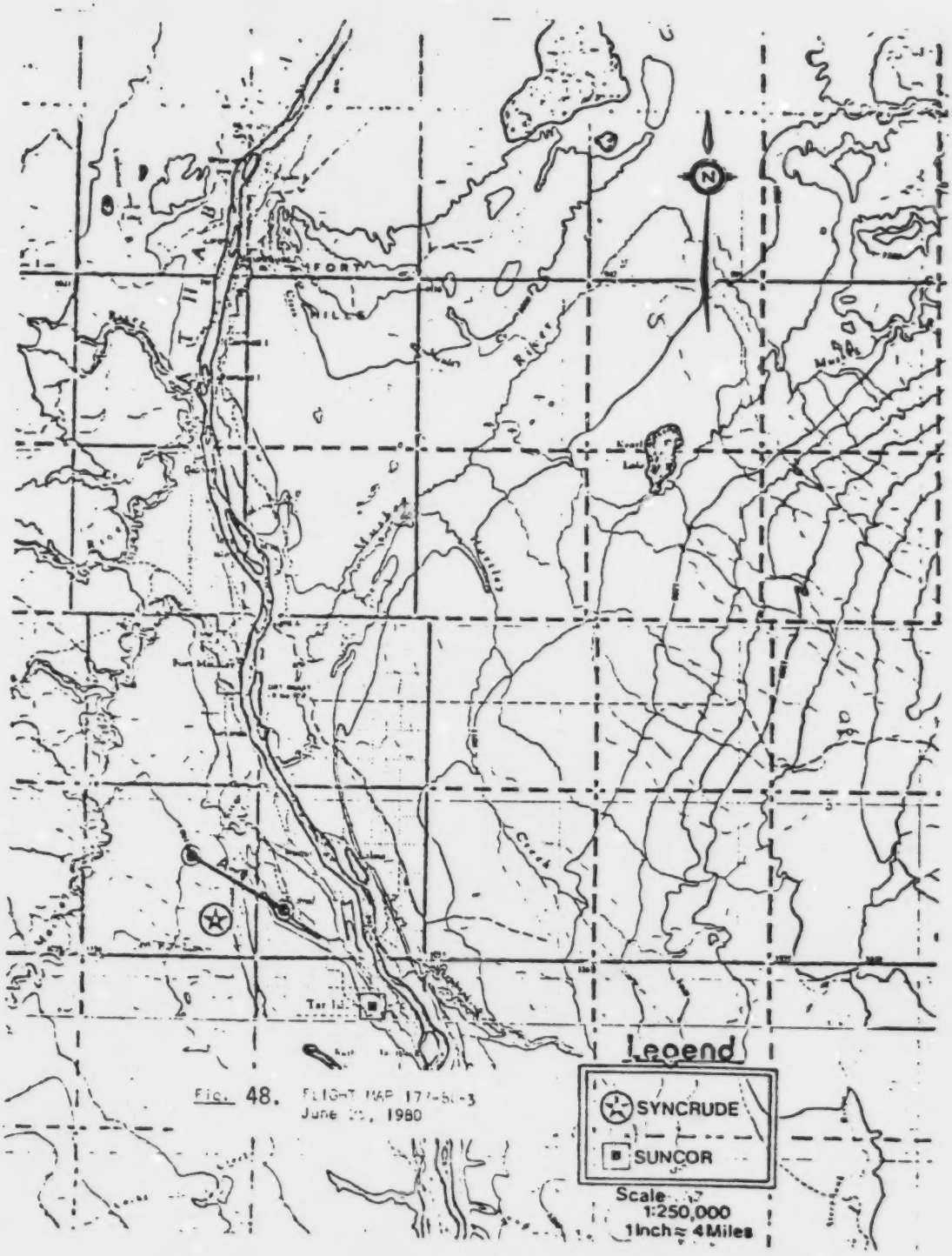


Fig. 48. FLIGHT MAP 17-SU-3
June 2[illegible], 1980

Table 39. Summary of measurements, 1980 March 25.

CASE NO. 085-80-1

Sample No.	Exposure Times	Location (Bearing from n.mi)	Source	Altitude (Feet)	Temp. (C^{o})	Filter Flow Rate (l/m)	Hi-Vol Flow Rate (cfm)	Remarks
Filters #3 & #4	1314-1400	110-060/6	Syncrude	4100' to 4500'	-	14.1	29	Wind shifted from northwest to southwest; climbed to 4500' after wind shift.
Filters #1 & E2	1425-1520	090/25	Syncrude and Suncor	4600'	-	14.2	29	Sampled combined plumes with secondary filter pack. Also exposed hi-vol filter.
Air Sample #2	1314-1400	110/060/6	Syncrude	4100' to 4500'	-	-	-	
Air Sample #3	1425-1520	090/25	Syncrude and Suncor	4600'	-	-	-	

Table 40. 1980 June 25 flight summary 177-80-3.

Sample. No.	Exposure Times	Location (Bearing from n.mi)	Source	Altitude (Feet)	T/Td (^{o}C)	Gas Analyzer Scale SO_2 ppb	NO_x ppm	O_3 ppm	Filter Flow Rate(l/m)	Hi-Vol Flow Rate (cfm)	Remarks
A 1	2115	360/1.5	Syncrude	2200	19/9	N/A	0.2	0.2	24	55	Hi-Vol A No SO_2 Data

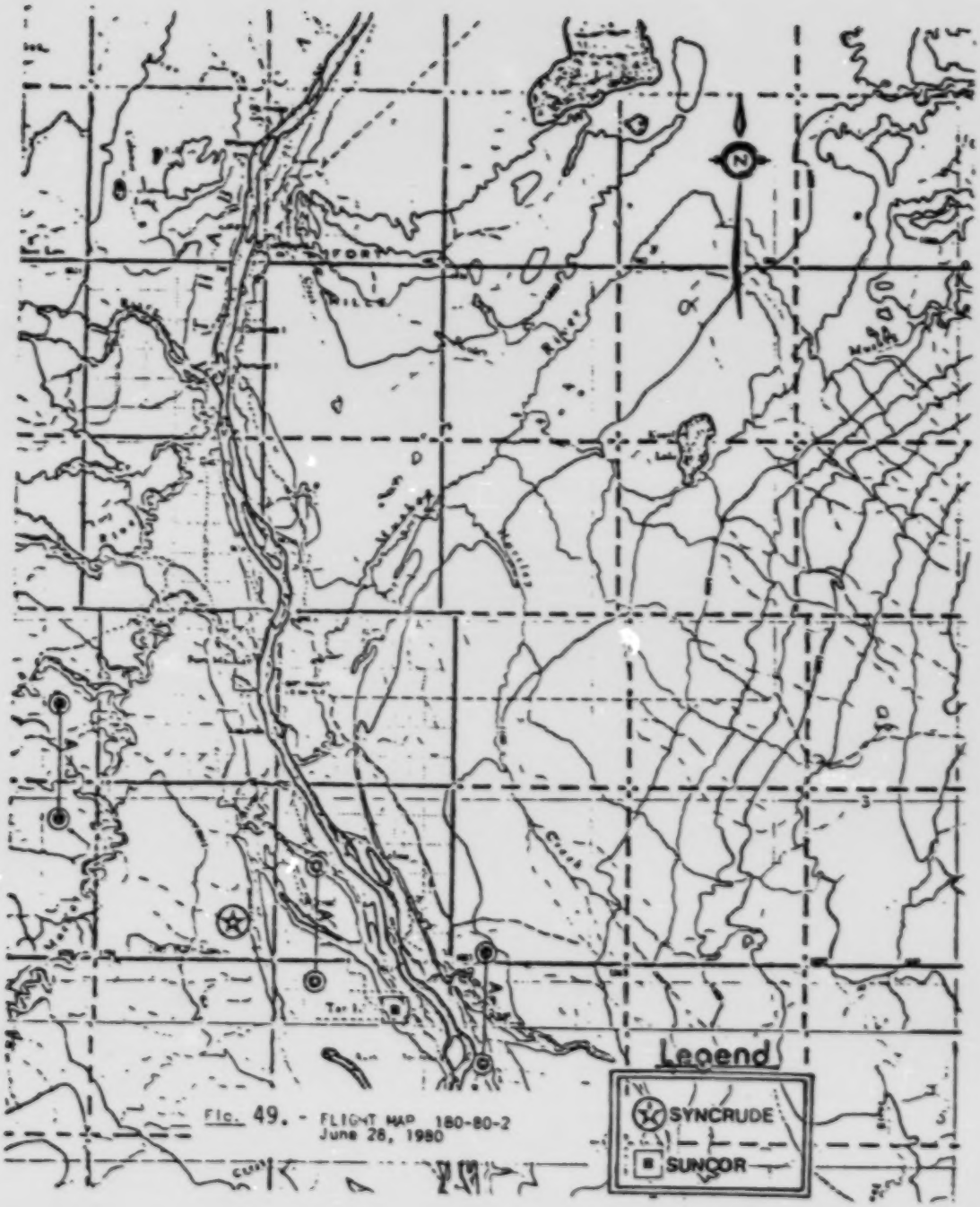


Fig. 49. - FLIGHT MAP 180-80-2
June 28, 1980

Table 41. 1980 June 28 flight summary 180-80-2.

Sample No.	Exposure Times	Location (Bearing from n.mi)	Source	Altitude (Feet)	T/Td (^{o}C)	Gas Analyzer Scale SO_2 ppb	NO_x ppm	O_3 ppm	Filter Flow Rate(l/m)	Hi-Vol Flow Rate(cfm)	Remarks
A 1	1250 1345	070/1	Syncrude	2800	13/6	N/A	0.2	0.2	21	50	SO_2 data unreliable
A 2	1420 1503	070/1	Suncor	2700	13.5/6	N/A	0.2	0.2	21	50	SO_2 data unreliable
A 3	1508 1530	250/3	Background	3000	13/5	N/A	0.2	0.2	21	50	SO_2 data unreliable

Table 42. Fort McMurray surface weather observations, 1980 July 04.

Time	Temperature/ Dew Point (^{o}C)	Wind Velocity (^{o}Mag/Knots)	Visibility (miles)	Pressure (in Hg)	Cloud Cover
0900	18/13	000/00	15	29.80	3000 SCT
1000	22/14	060/02	15	29.81	3000 BKN
1100	23/10	250/03	15	29.81	4500 SCT - 3000 BKN
1200	25/10	270/03	15	29.79	5600 SCT - 3000 BKN
1300	25/10	260/05	15	29.78	5600 SCT - 3000 BKN
1400	26/13	000/00	15	29.77	6000 SCT - 3000 BKN

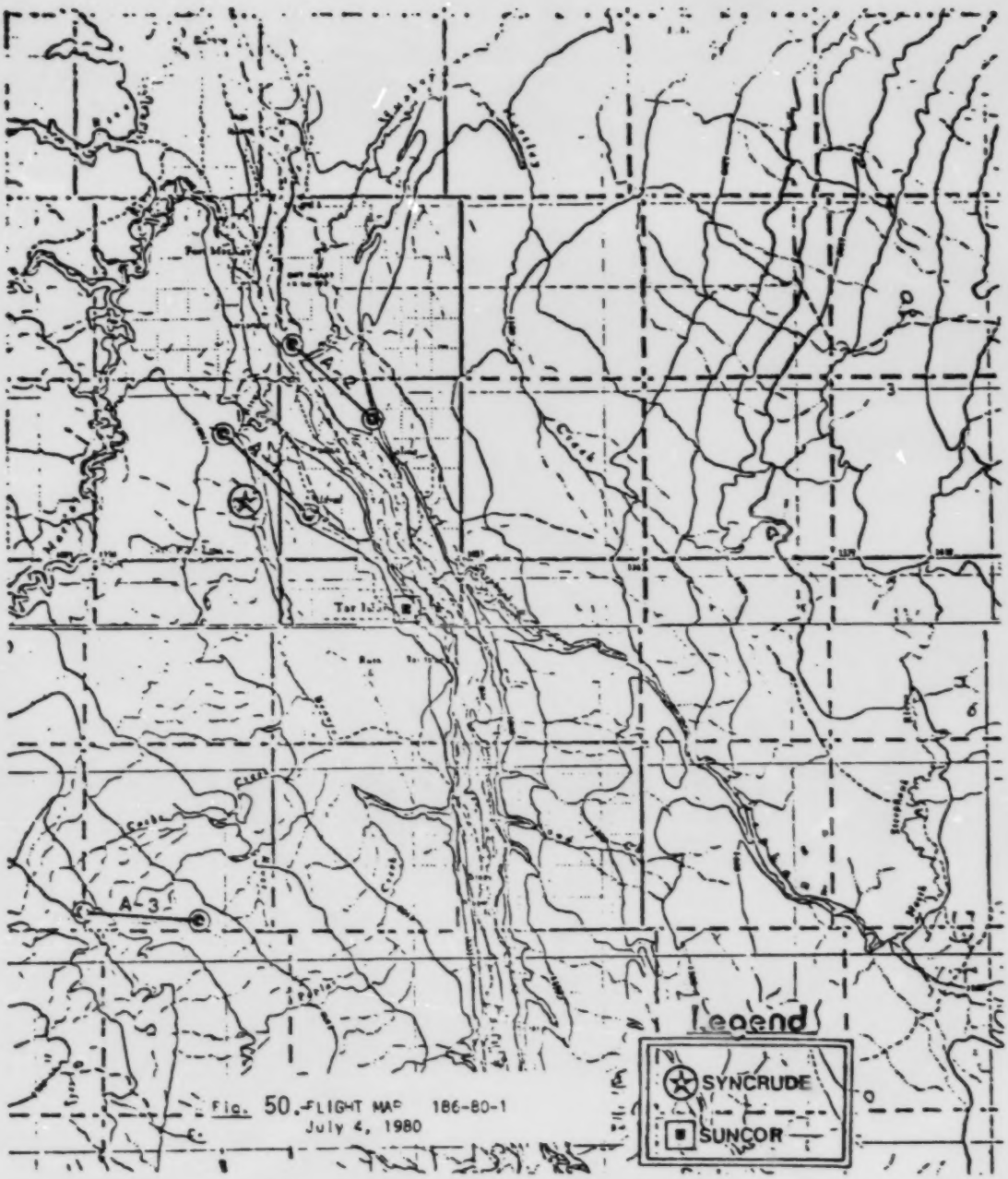


Fig. 50. FLIGHT MAP 186-80-1
July 4, 1980

the location of the two transects of the Syncrude plume, and the one upwind series. Table 43 summarizes the measurements made on this flight.

There was no aircraft sounding on this flight. However, the minisonde profile on Figure 51, taken at 1018, shows the surface mixed layer up to 4000' MSL with a neutral layer above. Note the aircraft temperatures at sampling height on this profile, along with the 1200 surface temperature at the airport.

6.2.14 1980 July 05, 0505-0845, 0920-0950

The flight on 05 July was an early morning, pre-convection case in which three separate samplings of the Syncrude plume were taken. Figure 52 depicts the location of the two close-in samples; the third was taken approximately 34 miles to the west of the plant.

Table 44 lists the weather observations at the Fort McMurray airport during the period of the flights. Figure 53 shows the pibal winds at the airport at 0600. Note the moderate easterly winds through 3000' MSL.

The aircraft landed at Mildred Lake to drop off the batch samples, and then conducted a sounding on its return to Fort McMurray. Figure 53 shows that the lowest layers were under a weak inversion, with a well-mixed layer above 3000'. The minisonde temperature profile, in Figure 54, also shows the weak inversion but with a more stable layer above.

Table 45 summarizes the measurements taken on this case day.

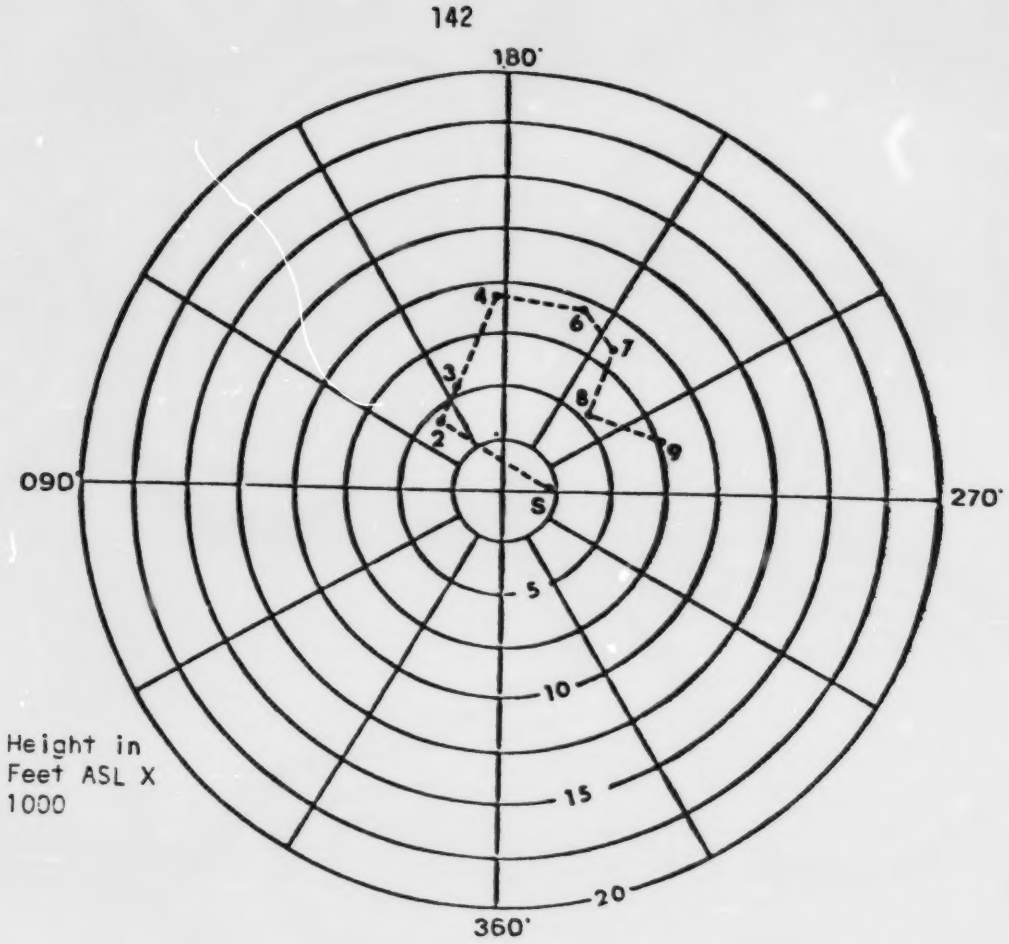
6.2.15 1980 July 07, 0510-0730, 1030-1205, 1340-1605, 1805-1930

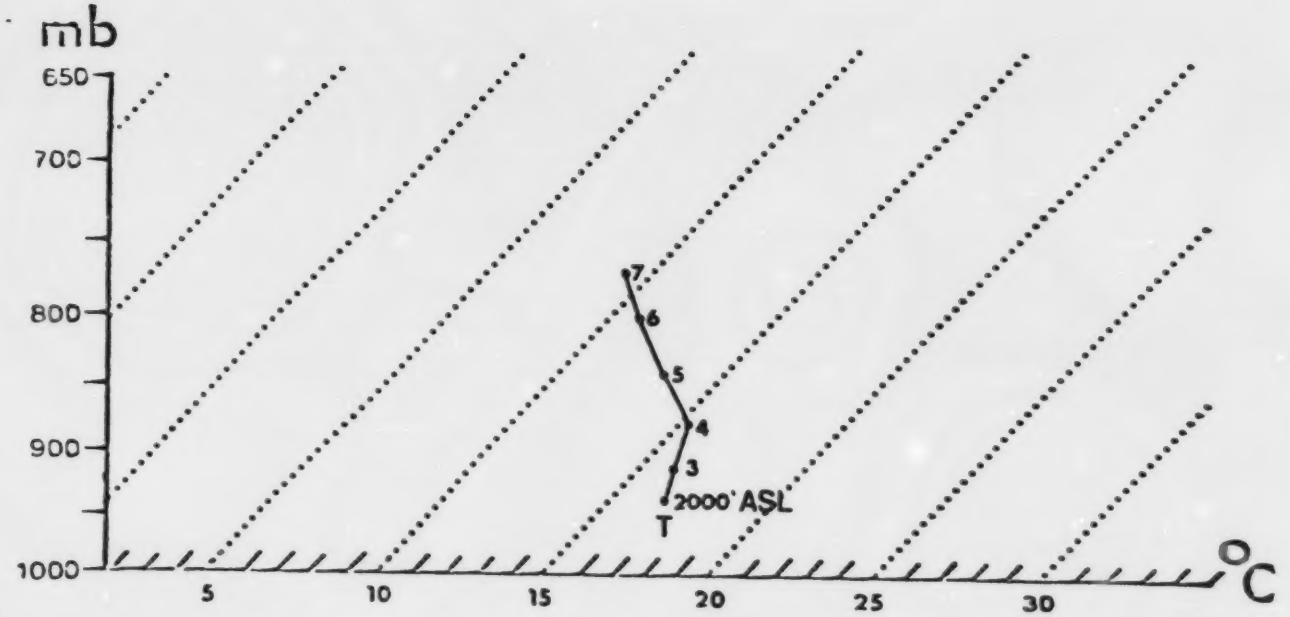
A number of case samples were conducted on this day. The first was a morning pre-convection case of the Syncrude plant. Table 46 lists the weather observations at the airport. Note the calm winds and thin fog at Fort McMurray during the early morning hours.

Figure 55 shows the locations of th first sampling flight of the day. Sample run #1 was conducted 25 miles east of Syncrude, in the region of the Muskeg Forestry Tower. On completion of this run, the

Table 43. 1980 July 04 flight summary 186-80-1.

Sample No.	Exposure Times	Location (Bearing from n.mi)	Source	Altitude (Feet)	T/Td (^{o}C)	Gas Analyzer Scale SO_2 ppb	NO_x ppm	O_3 ppm	Filter Flow Rate(l/m)	Hi-Vol Flow Rate(cfm)	Remarks
A 1	1010 1111	020.1	Syncrude	2700	21.5/8.5	1000	0.2	0.2	18	50	HV - F FP 1&2
A 2	1120 1225	010/5	Syncrude	3300	19.5/8.0	500	0.2	0.2	17	50	HV - G FP 3&4
A 3	1240 1310	190/15	Background	3500	19.0/8.0	100	0.2	0.2	17	50	HV - H FP 1&2 (loose pack)





July 4, 1980
Hodograph (YMX Airport) 1200
Sounding (Minisonde) 1018

FIG. 51.

U

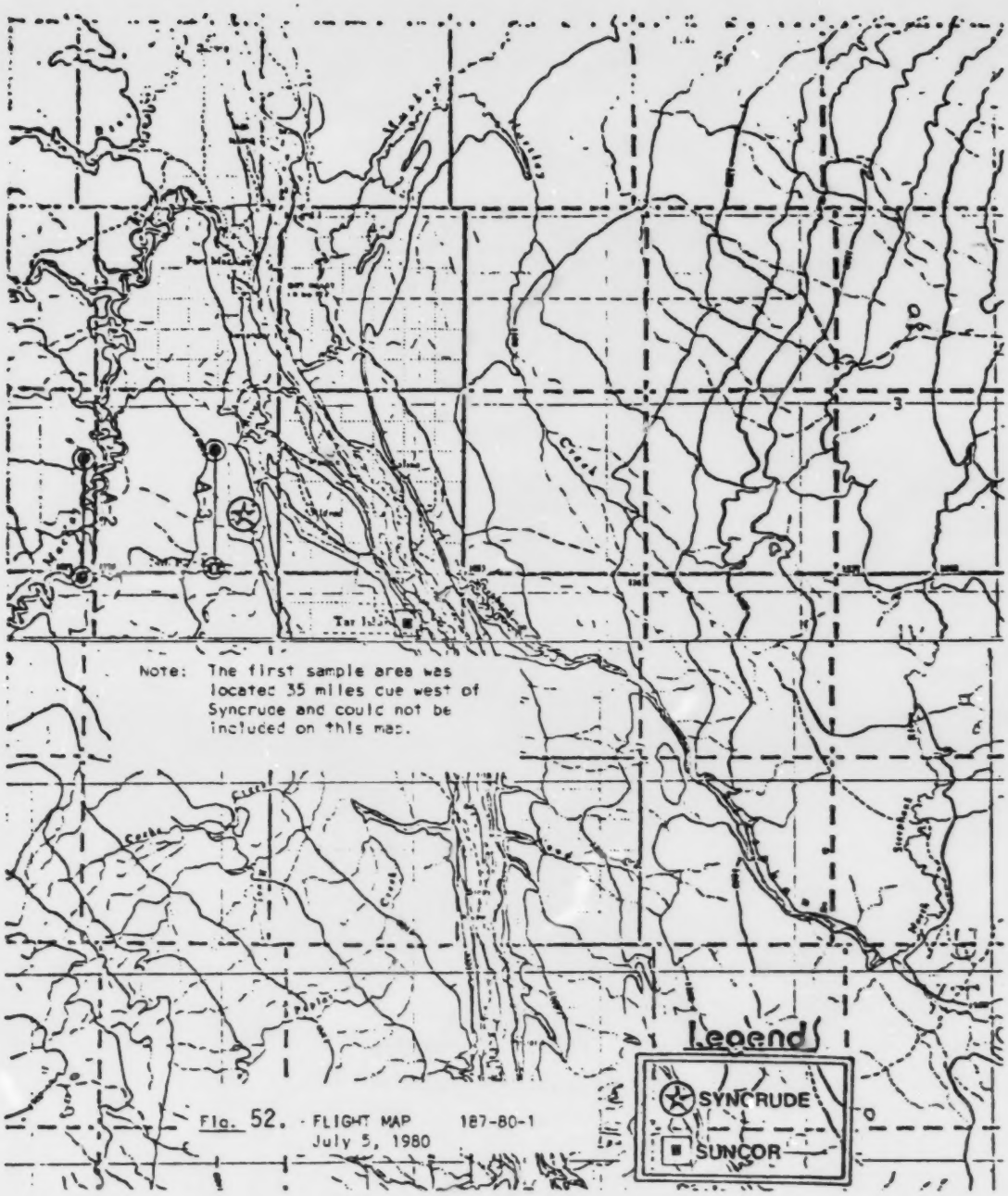
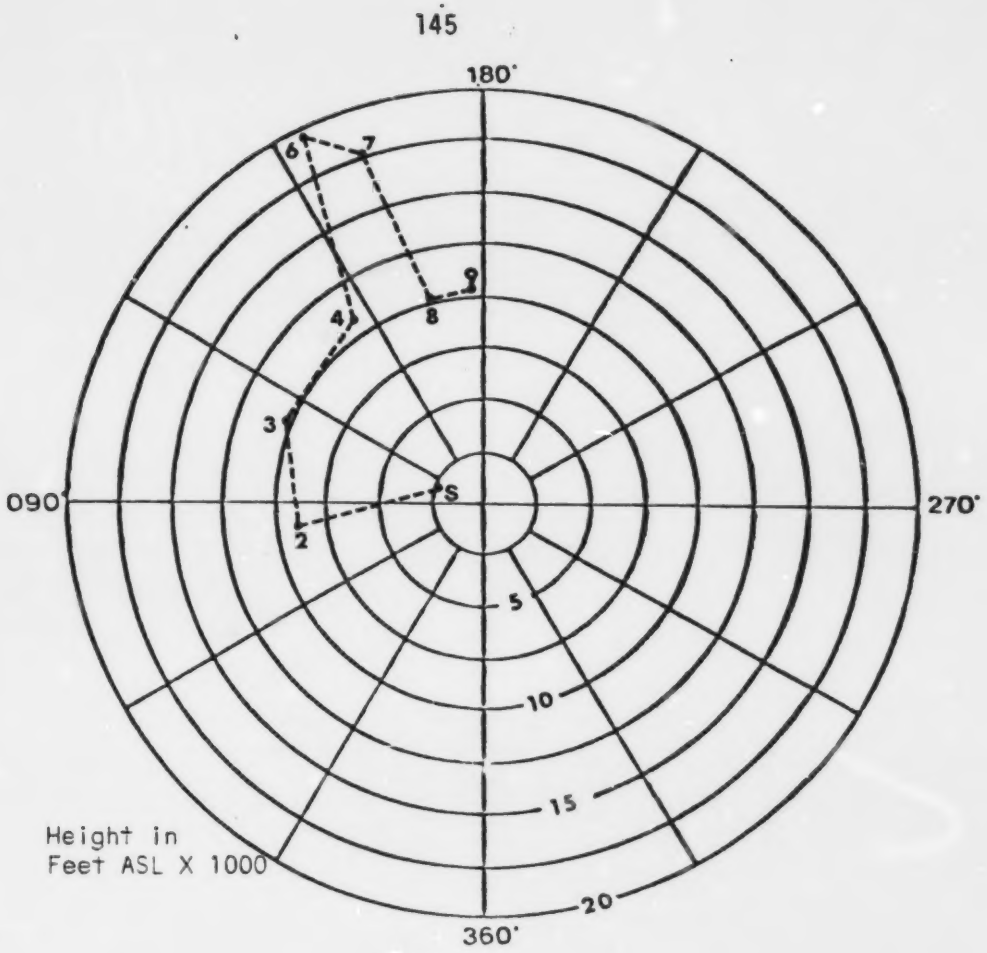
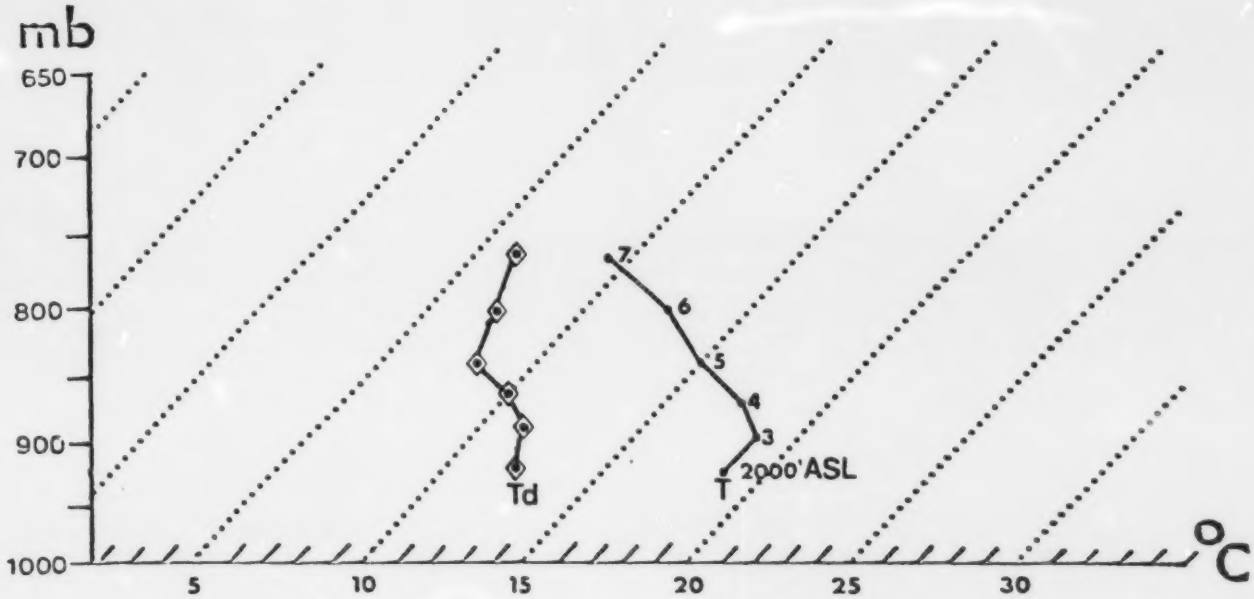

Note: The first sample area was located 35 miles due west of Syncrude and could not be included on this map.
Legend
SYNCRUDE
SUNCOR

Fig. 52. - FLIGHT MAP 187-80-1
July 5, 1980

Table 44. Fort McMurray surface weather observation, 1980 July 05.

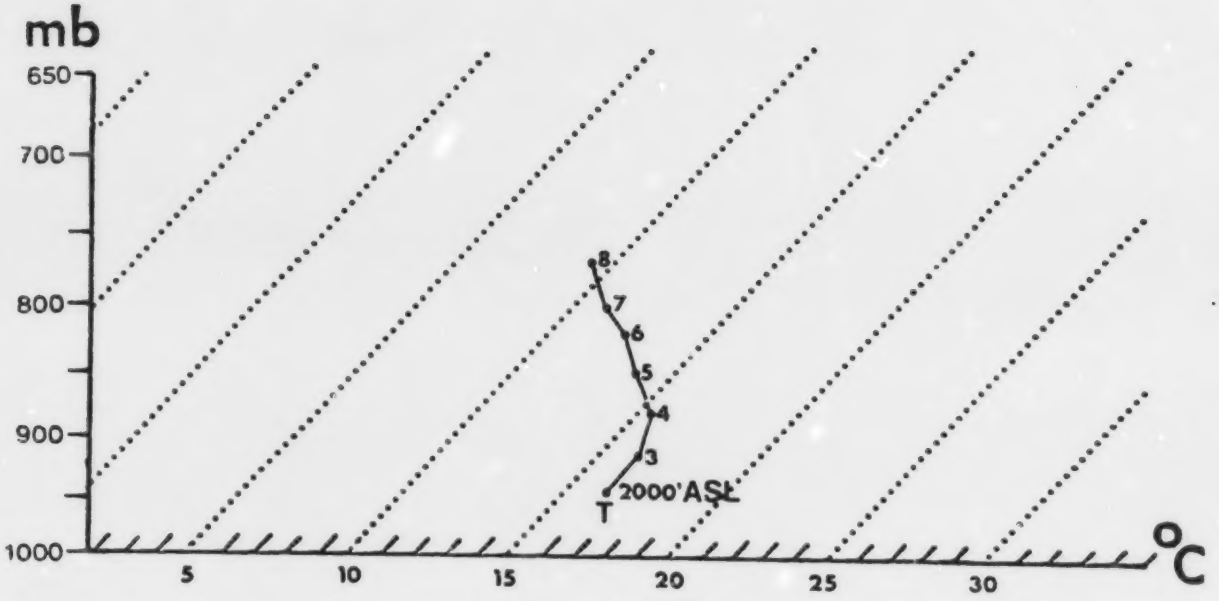
Time	Temperature/ Dew Point (^{o}C)	Wind Velocity (^{o}Mag/Knots)	Visibility (miles)	Pressure (in Hg)	Cloud Cover
0400	15/12	100/07	15	29.72	9000 SCT
0500	14/12	100/06	15	29.71	5000 SCT
0600	15/12	100/08	15	29.70	11000 SCT
0700	17/12	100/08	15	29.69	10000 SCT
0800	18/12	120/03	15	29.68	11000 SCT
0900	19/13	060/06	15	29.66	11000 SCT
1000	20/14	040/06	15	29.65	4200 SCT
1100	23/14	050/09	15	29.64	11000 SCT





July 5, 1980
Hodograph (YMM Airport) 0600
Sounding 0930

FIG. 53.



July 5, 1980
Sounding (Minisonde) 1008

FIG. 54.

Table 45. 1980 July 05 flight summary 187-80-1.

Sample No.	Exposure Times	Location (Bearing from n.mi)	Source	Altitude (Feet)	T/Td (^{o}C)	Gas Analyzer Scale SO_2 ppb	NO_x ppm	O_3 ppm	Filter Flow Rate(l/m)	Hi-Vol Flow Rate(cfm)	Remarks
A 1	0515 0645	250/35	Syncrude	2800	19/11	1000	0.2	0.2	18	50	HV - 1 FP 1&2
A 2	0650 0755	250/5	Syncrude	2800	18.5/11	1000	0.2	0.2	18	50	HV - J FP 3&4
A 3	0800 0835	250/1	Syncrude	2700	20/11.5	1000	0.2	0.2	18	50	HV - K FP 1&2 (loose pack)

Table 46. Fort McMurray surface observation, 1980 July 07.

Time	Temperature/ Dew Point (°C)	Wind Velocity (°Mag/Knots)	Visibility (miles)	Pressure (in Hg)	Cloud Cover
0500	8/7	000/00	10	29.87	Fog
0600	9/8	000/00	8	29.88	Fog
0700	10/8	000/00	8	29.88	Fog
0800	11/9	000/00	10	29.88	Fog
0900	13/10	000/00	15	29.80	10000 SCT
1000	16/11	030/03	15	29.85	25000 SCT
1100	19/13	000/00	10	29.84	18000 SCT
1200	23/12	230/07	6	29.82	4000 SCT
1300	23/12	230/09	6	29.81	4000 SCT
1400	23/12	240/04	6	29.81	4000 SCT
1500	23/12	210/07	8	29.80	4000 SCT
1600	25/12	240/09	9	29.77	4000 SCT
1800	27/11	240/06	10	29.72	7000 SCT
1900	27/11	240/06	10	29.70	7000 SCT
2000	25/11	240/08	10	29.71	7000 SCT

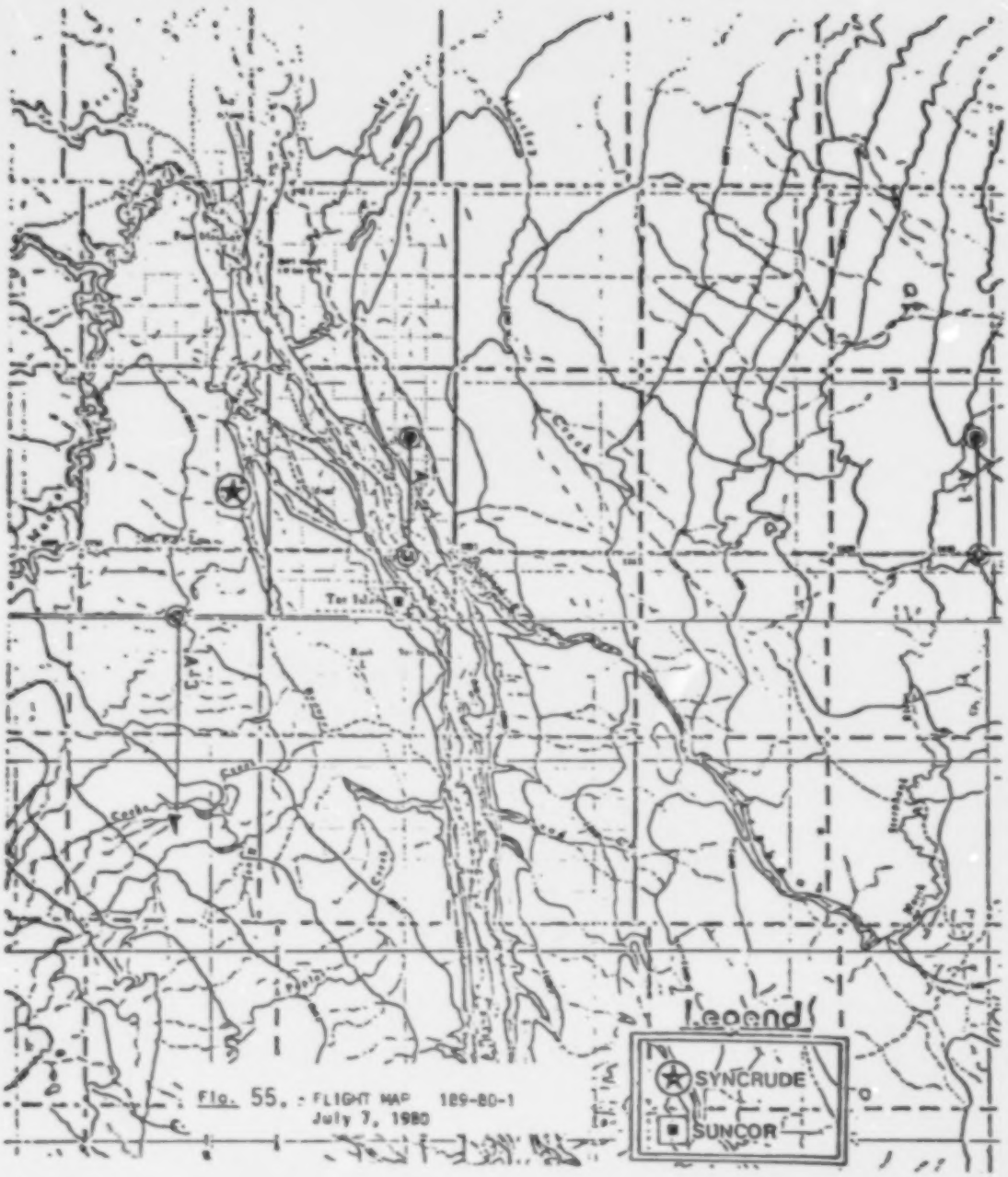


Fig. 55. - FLIGHT MAP 129-80-1
July 7, 1980

aircraft was positioned 6 miles east of Syncrude, over the river. Flight visibility on this run was estimated at 2 miles in smoke and haze. The background sample was conducted on the return flight to the Fort McMurray airport, starting from southwest of the Syncrude plant. The flight data from these three sample areas are summarized in Table 47.

A temperature sounding was conducted just prior to the first set of samples, and is shown in Figure 56. Note the very shallow surface inversion, which accounted for the thin fog cover during the early hours. The Syncrude acoustic sounder profile is shown in this same figure, which shows the very light westerly winds just above the surface.

After refueling, the aircraft conducted a second set of runs, as shown in Figure 57. Two samples were collected from the Syncrude plume, one at one mile and the other at six miles downwind. The wind profile from the acoustic sounder, seen in Figure 58, showed a stronger southwesterly flow at plume height than was seen earlier in the day.

The aircraft landed at Mildred Lake to drop off the samples, and then returned to Fort McMurray for fuel. The third sampling flight of the day was conducted during the early afternoon, as shown in Figure 59. The first two samples taken on this flight were to search for an "ozone bulge" in the Syncrude plume. Several transects were made before this bulge was encountered. The third sample was conducted over the river, approximately six miles north-east of the plant. The plume concentrations were very low during this third sample, due to convective mixing of the plume. The plume was not visibile during the runs, and was not encountered regularly due to the turbulence at the sampling levels.

A fourth sampling flight was conducted, after the plane was refueled at Fort McMurray as shown in Figure 60. The flight conditions during the evening hours were much smoother than the previous flight. The first set of runs was made 12 miles to the east of the Suncor plant in an attempt to collect ozone data on this plume. However, flight visibility was very poor due to low convective clouds overhead, and the

Table 47. 1980 July 07 flight summary 189-80-1.

Sample No.	Exposure Times	Location (Bearing from n.mi)	Source	Altitude (Feet)	T/Td (^{0}C)	Gas Analyzer Scale SO_2 ppb	NO_x ppm	O_3 ppm	Filter Flow Rate(l/m)	Hi-Vol Flow Rate(cfm)	Remarks
A 1	0530 0630	070/25	Syncrude	2500	17/2	1000	0.2	0.2	23	50	HV - L FP 1&2
A 2	0650	100/6	Syncrude	3300	16/4.5	500	0.2	0.2	N/A	N/A	HC - Bag only
A 3	0700	200/10	Background	3000	17.5/4	100	0.2	0.2	N/A	N/A	HC - Bag only

Table 47. Continued. 1980 July 07 flight summary 189-80-2.

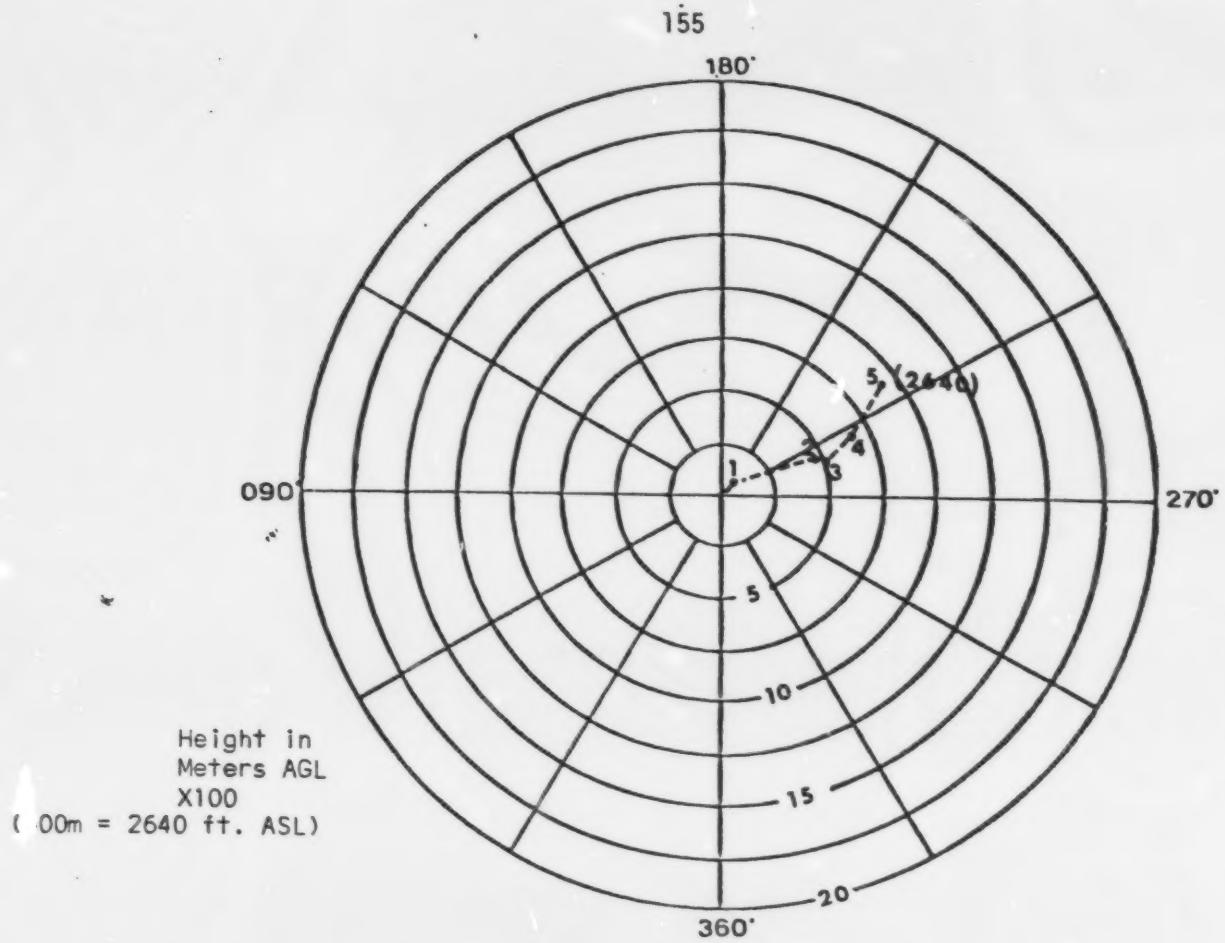
Sample No.	Exposure Times	Location (Bearing from n.mi)	Source	Altitude (Feet)	T/Td (°C)	Gas Analyzer Scale SO_2 ppb	NO_x ppm	O_3 ppm	Filter Flow Rate (l/m)	Hi-Vol Flow Rate (cfm)	Remarks
A 1	1040 1125	045/6	Syncrude	2600	18/6	500	0.2	0.2	24	50	HC-Bag #4 HV-M FP 2&3
A 2	1130 1200	045/1	Syncrude	2300	18.5/11	1000	0.2	0.2	21	50	HC-Bag #3 HV-N FP 1&4

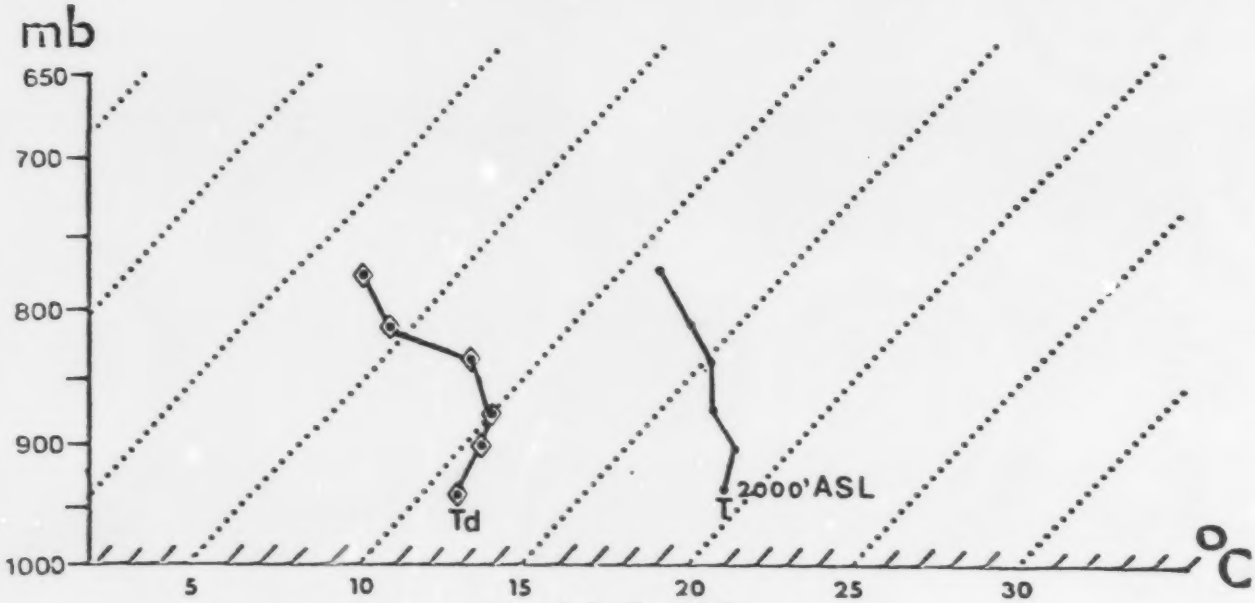
Table 47. Continued. 1980 July 07 flight summary 189-80-4.

Sample No.	Exposure Times	Location (Bearing from n.mi)	Source	Altitude (Feet)	T/Td (°C)	Gas Analyzer Scale SO_2 ppb	NO_x ppm	O_3 ppm	Filter Flow Rate(l/m)	Hi-Vol Flow Rate(cfm)	Remarks
A 1	1400	020/30	Syncrude	2700	19.5/11.5	50	0.2	0.2	N/A	N/A	Bag #6
A 2	1420	040/20	Syncrude	2600	21/12.5	50	0.2	0.2	N/A	N/A	No Samples
A 3	1445 1600	045/6	Syncrude	2800	21/12	50	0.2	0.2	21	50	HC-Bag #7 HV-0 FP - 1&2 Convective Day

Table 47. Concluded. 1980 July 07 flight summary 189-80-6.

Sample No.	Exposure Times	Location (Bearing from n.mi)	Source	Altitude (Feet)	T/Td (^{0}C)	Gas Analyzer Scale SO_2 ppb	NO_x ppm	O_3 ppm	Filter Flow Rate(l/m)	Hi-Vol Flow Rate(cfm)	Remarks
A 1	1820 1830	09G/12	Suncor	2700	23/9.5	100	0.2	0.2	N/A	N/A	No samples
A 2	1838 1928	090/6	Syncrude	2700	22.5/10.5	100	0.2	0.2	24	51	HC-Bag #8 HV-P FP - 1&2 Day





July 7, 1980
Hodograph (Acoustical Sounder) 0600 - 0630
Sounding 0520

FIG. 56.

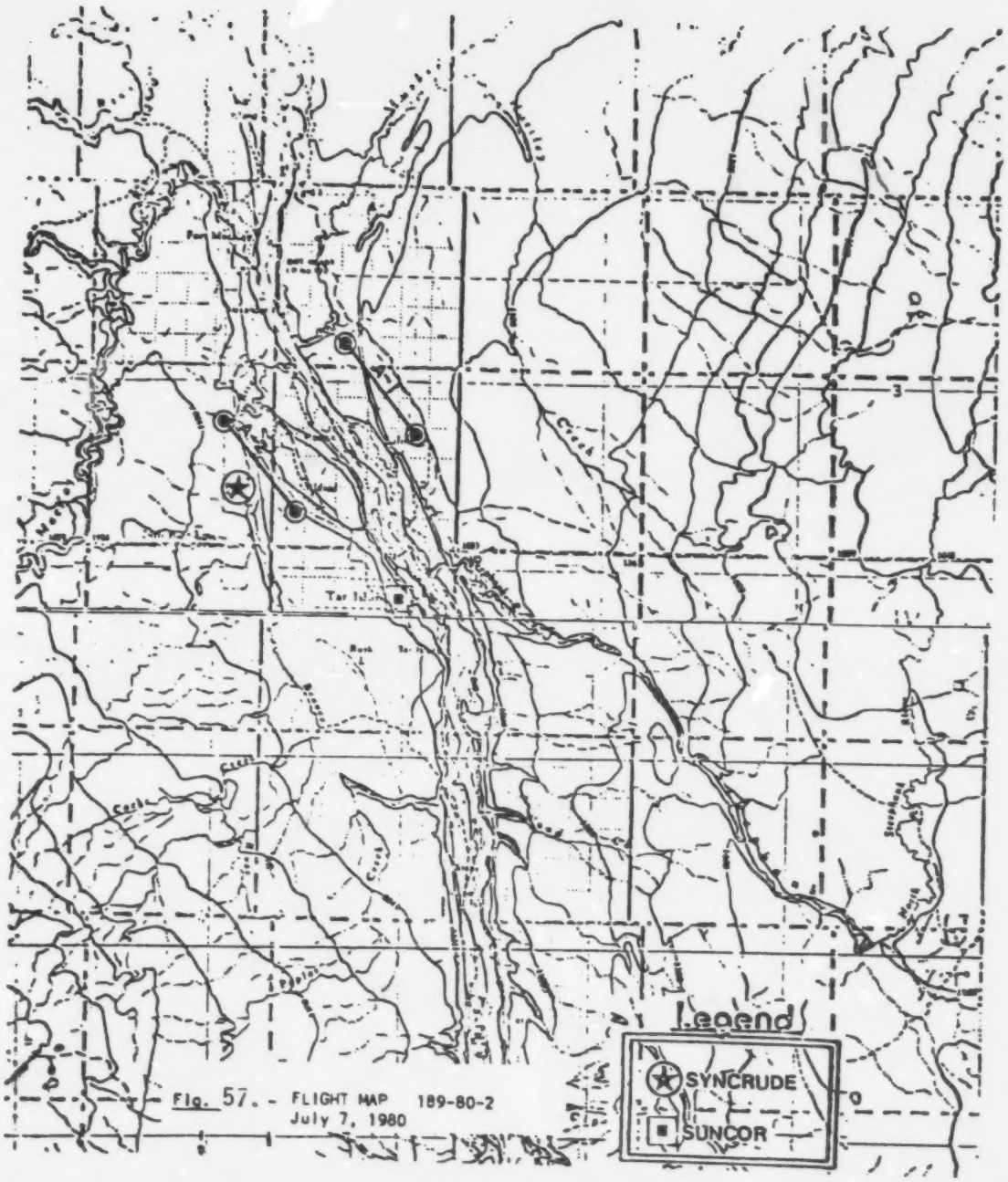
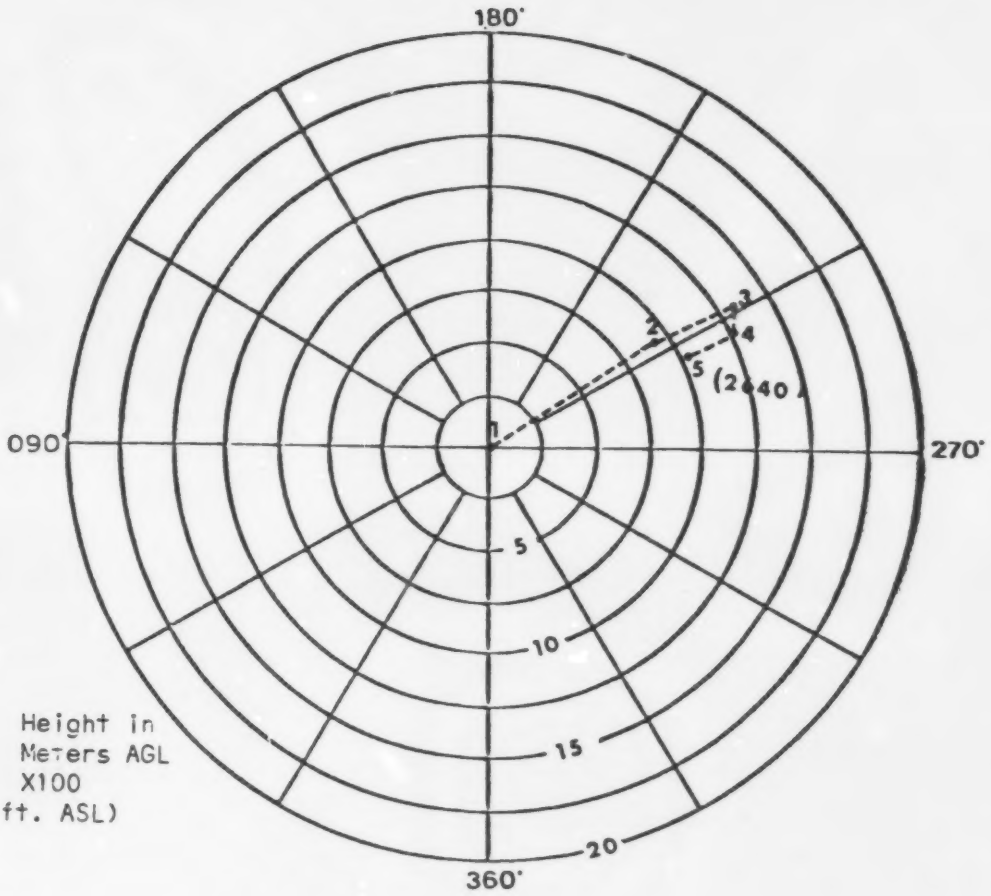
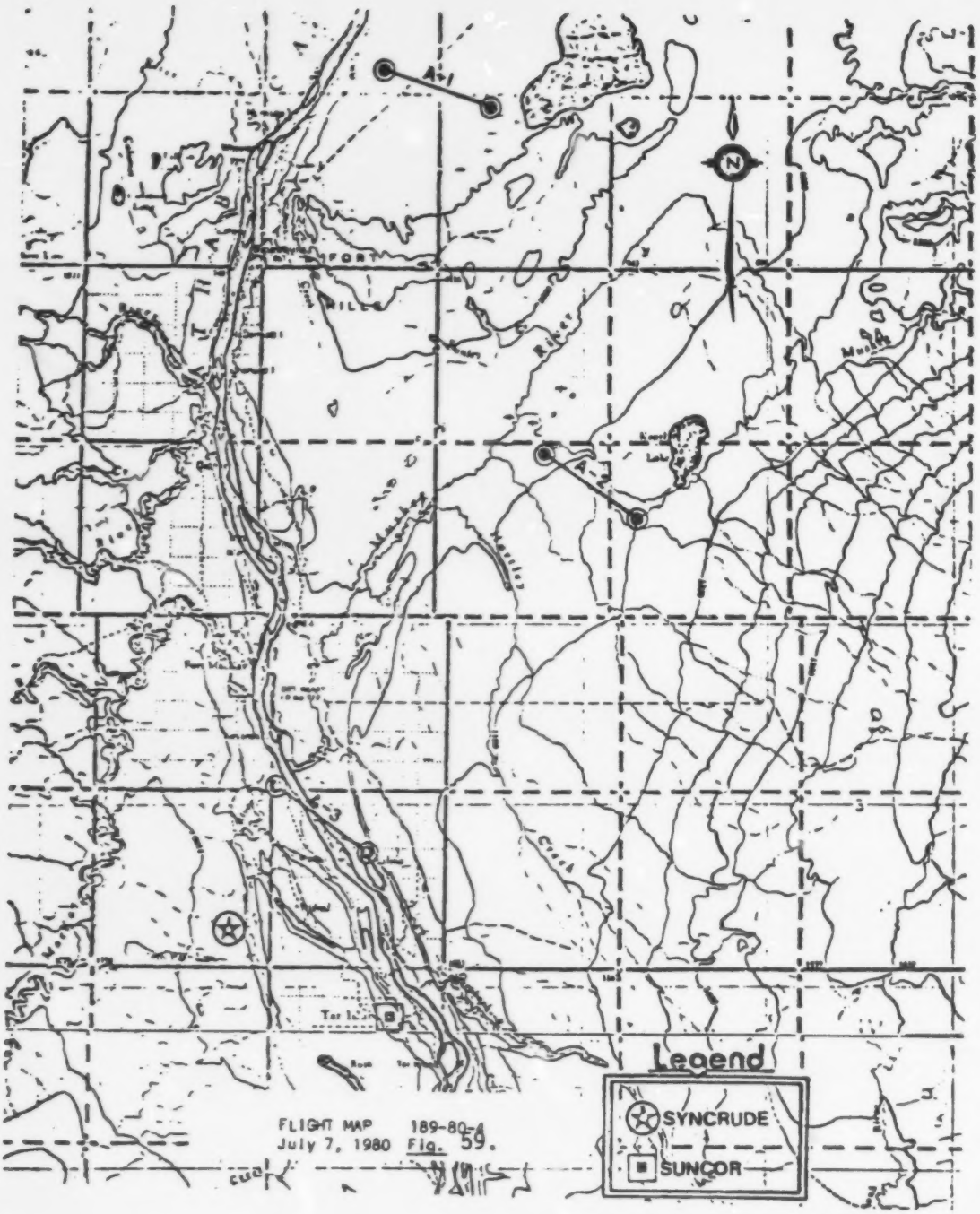


Fig. 57. - FLIGHT MAP 189-80-2
July 7, 1980



July 7, 1980
Hodograph (Acoustical Sounder) 0700 - 0730

FIG. 58.



FLIGHT MAP 189-80-4
July 7, 1980 Fig. 59.

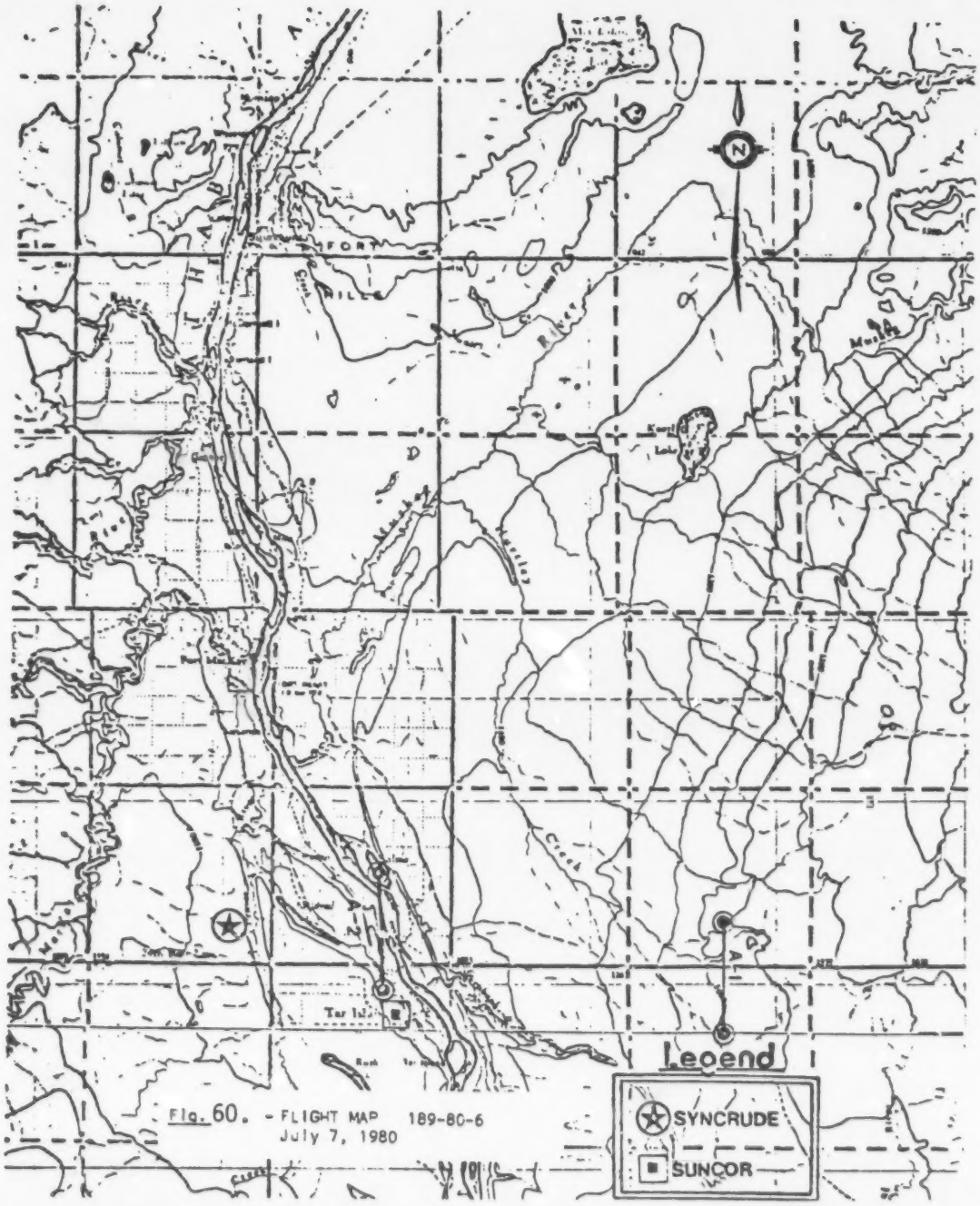


Fig. 60. - FLIGHT MAP 189-80-6
July 7, 1980

plume was not detected. The aircraft was repositioned to sample the Syncrude plume at a downwind distance of approximately 6 miles.

6.2.16 1980 July 08, 1005-1235, 1345-1635

The final case day in this field program was conducted on 08 July. Two sampling flights were flown, the first during mid-morning inversion breakup, and the second one during convective mixing. Figure 61 shows the sampling locations of the first flight. Plume traverses were made in the Syncrude plume at 1.5 and 6 miles downwind.

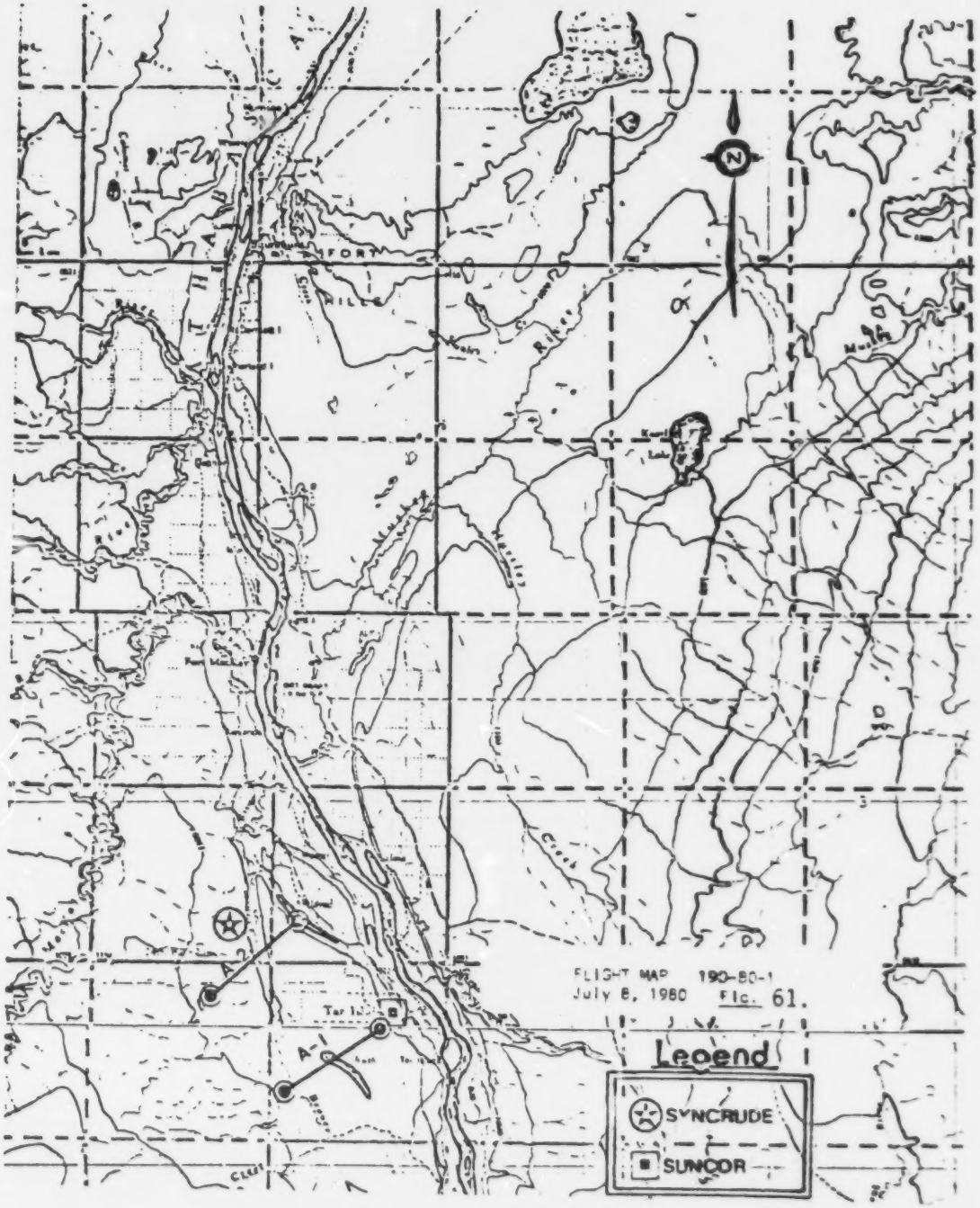
The surface weather observations are shown in Table 48, which revealed light winds and high scattered clouds. After the sampling runs were completed, a temperature sounding was conducted between the surface and 7000' MSL (at 1200 hours). This sounding is shown in Figure 62.

After refueling at Fort McMurray, the aircraft was launched for a second sampling flight. Figure 63 shows the location of two of the three-plume transects. The purpose of this flight was, again, to look for evidence of an ozone bulge to the plume concentration in the Syncrude plume.

The first data sample was made at various distances downwind from the plant, and flown between cloud base (5900' MSL) and cloud top (7500' MSL) of the scattered cumulus cloud cover. Surface winds were light and variable, and the plume was seen to rise to 5500' before levelling off.

An aircraft sounding conducted at 1400 is shown in Figure 64, which shows the well-mixed layer between the surface and 8000' MSL. Following the sounding, two sets of runs were made in the Suncor plume. The first one was conducted at 3.5 miles east of the plant, and the second at 8 miles downwind. Table 49 summarizes the measurements made on this day.

Upon completion of this set, the aircraft was flown to Mildred Lake to drop off the samples and prepare for return to Calgary. It was decided that sufficient data were gathered for this field study to terminate, and the aircraft and crew departed the Oil Sands region later that evening.



FLIGHT MAP 190-80-1
July 8, 1980 Fig. 61.

Table 48. Fort McMurray surface weather observation, 1980 July 08.

Time	Temperature/ Dew Point (°C)	Wind Velocity (°Mag/Knots)	Visibility (miles)	Pressure (in Hg)	Cloud Cover
0600	13/10	220/03	15	29.75	9000 SCT
0700	14/11	000/00	15	29.76	9000 SCT
0800	17/11	280/05	15	29.75	10000 SCT
0900	18/13	300/02	15	29.76	22000 SCT
1000	19/13	360/04	15	29.75	23000 SCT
1100	22/12	270/01	15	29.75	4000 SCT
1200	23/12	310/02	15	29.74	4500 SCT
1300	24/12	320/05	15	29.72	4800 SCT
1400	26/12	300/06	15	29.71	5500 SCT
1500	26/13	330/05	15	29.69	5000 SCT
1600	27/10	330/06	15	29.68	6000 SCT
1700	28/10	360/05	15	29.67	6000 SCT

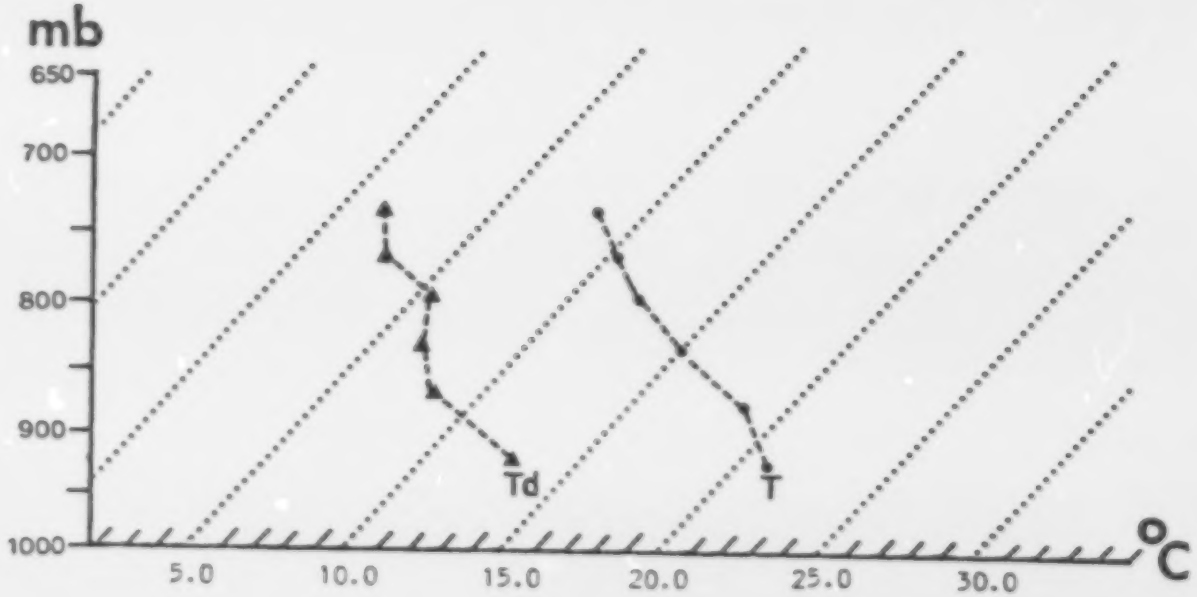


Fig. 62. Temperature Sounding
July 8, 1980 1200 Hrs.

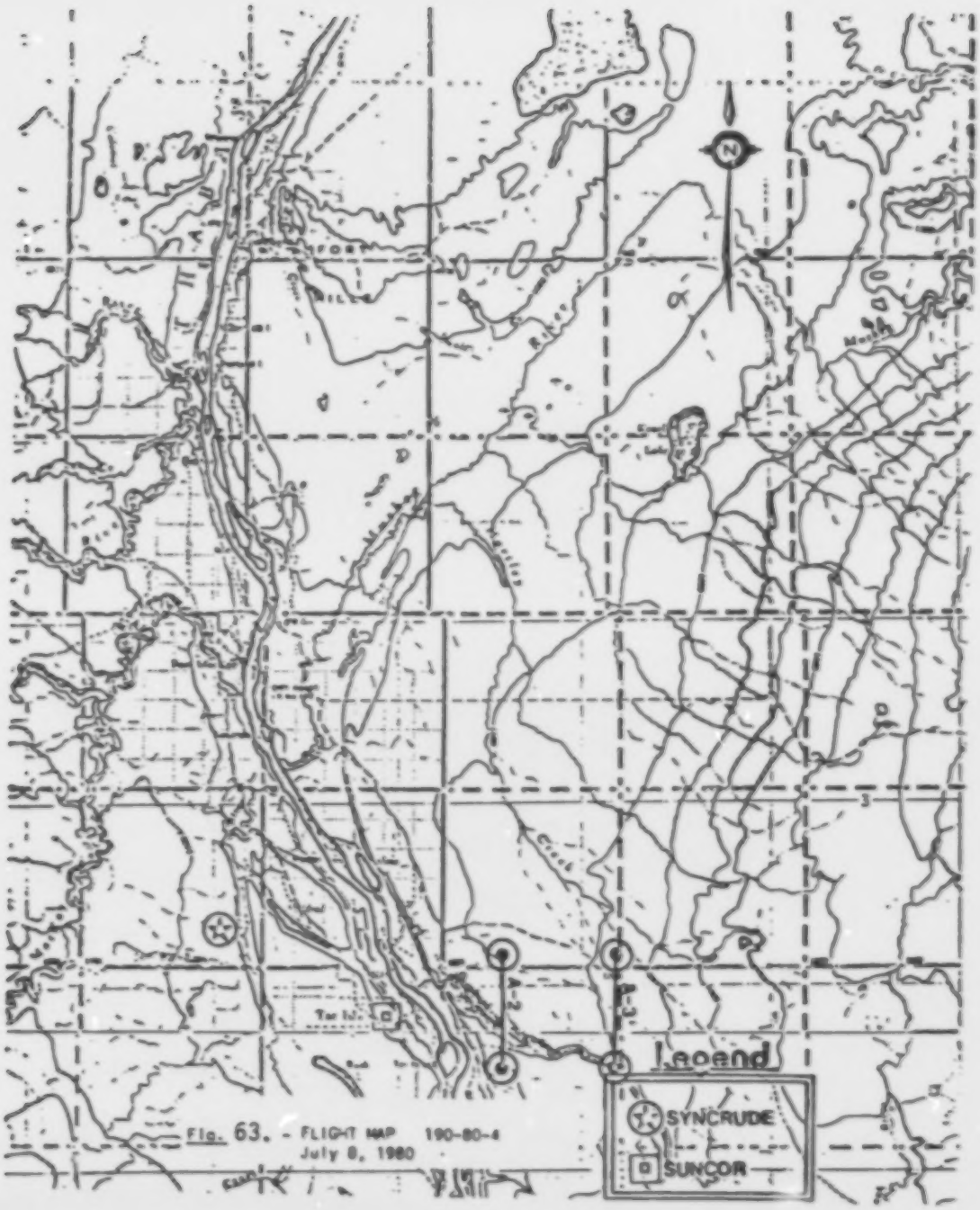
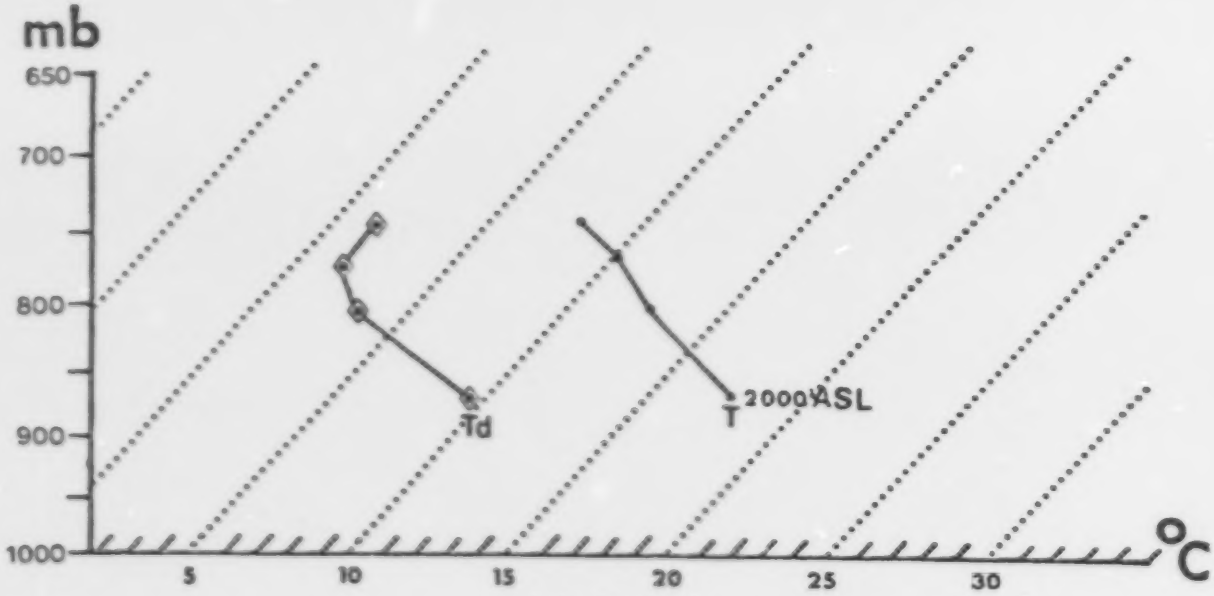


Fig. 63. - FLIGHT MAP 190-80-4
July 8, 1980



July 8, 1980
Sounding 1400

FIG. 64.

Table 49. 1980 July 08 flight summary 190-80-1.

Sample No.	Exposure Times	Location (Bearing from n.mi)	Source	Altitude (Feet)	T/Td (°C)	Gas Analyzer Scale SO_2 ppb	NO_x ppm	O_3 ppm	Filter Flow Rate(l/m)	Hi-Vol Flow Rate(cfm)	Remarks
A 1	1045 1125	136/6	Syncrude	3000	18.5/9	1000	0.2	0.2	23	50	HC-Bag #1 HV-Q FP - 1&2
A 2	1129 1159	135/1.5	Syncrude	2900	18/8.5	1000	0.2	0.2	23	50	HC- HV-P FP - 3&4

Table 49. Continued. 1980 July 08 flight summary 190-80-4.

Sample No.	Exposure Times	Location (Bearing from n.mi)	Source	Altitude (Feet)	T/Td (°C)	Gas Analyzer Scale SO_2 ppb	NO_x ppm	O_3 ppm	Filter Flow Rate(l/m)	Hi-Vol Flow Rate(cfm)	Remarks
A 1	1350 1455	090/5-10	Syncrude	7000*	-	500	0.2	0.2	-		
A 2	1530 1546	090/3.5	Suncor	4400	17.5/8.5	500	0.2	0.2	-	75	Hi-Vol S No nitrate filter HC-Bag #3
A 3	1555 1610	090/8-9	Suncor	4600	17/8	500	0.2	0.2	-	75	Hi-Vol T

* The altitude of the aircraft varied from 5500' ASL to 7500'. 7000' is only put down as a rough average.

6.3 FILTER PACK SAMPLING

6.3.1 Analytical Methods[1]

6.3.1.1 Filter pack design. Two types of filter packs were used for the sampling--a low volume filter pack and a high volume filter pack.

6.3.1.1.1 Low Volume filter pack. A diagram of the filter holder used in this study is shown in Figure 65. The back section of the filter was a Millipore Swinnex 47 mm polypropylene filter holder. The front section was machined from Teflon to match the Swinnex holder. Four of these holders were clamped between two pieces of aluminum plate held together with a bolt and wingnut. A Fluoropore FS-3 μm 47 mm diameter filter (Millipore) was used for the particulate filter. The nitric acid filter was 47 mm diameter sodium chloride impregnated Whatman 41. Two 47 mm diameter glycerol-potassium carbonate impregnated Whatman 41 filters were used to absorb the SO_2.

Flow through the filter pack was obtained by routing the exit line from the filter pack to Venturi exhaust. No pump was employed.

6.3.1.1.2 High Volume filter pack. The high volume filter pack consisted of 8 x 10 filters separated by stainless steel screens. The particulate filter was 8 x 10 inches Whatmann 40. The nitric acid and SO_2 filters were 8 x 10 inches sheets of sodium chloride or glycerol-potassium carbonate impregnated Whatman 41.

During March, the exhaust line from the hi-vol sampler was routed to a Venturi exhaust. In restropect this arrangement probably meant that flow through the sampler was largely due to ram air effects. During June/July flow was further increased by installing an air blower after the sampler.

---

[1] This section was authored by Dr. J.M. Gray, Alberta Research Council, Edmoton, Alberta

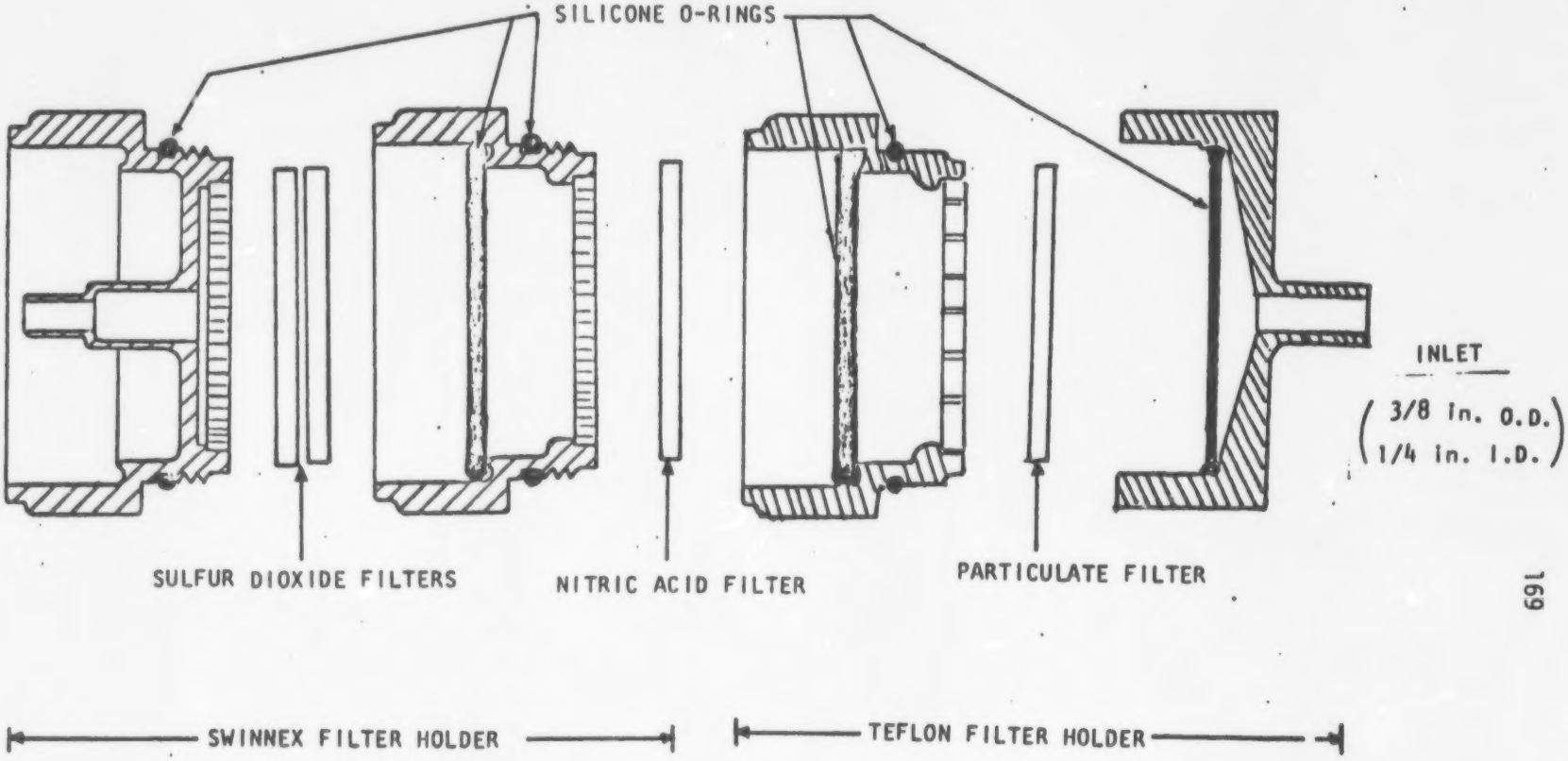


Figure 65. Cutaway diagram of low volume filter holder.

6.3.1.2 Preparation of filters. All impregnated filters were prepared by impregnating 8 x 10 Whatmann 41 filter papers. A Spiratone Photo Stabilization Processor was used to impregnate the filter papers and roll out the excess impregnant. A schematic of the processor is shown in Figure 66. The appropriate impregnant was placed in the liquid tank and dry filter papers inserted into the processor. The paper was carried through the impregnating solution and the excess moisture rolled out in approximately 15 seconds. The papers were then dried in an oven. The nitric acid filters were impregnated using a 5% sodium chloride solution and dried at 90°C. This method has been well documented by Okita et al. (1976) and Forrest et al. (1979). The SO_2 filters were impregnated using 10% v/v glycerol and 25% w/v potassium carbonate solution (Lusis et al. 1977) and dried at 50°C. The 47 mm diameter filters for the low volume filter pack were cut from the 8 x 10 sheets using a stainless steel punch. The 8 x 10 filters were stored in polyethylene bags until used. The 47 mm filters were stored in the original Millipore plastic containers.

6.3.1.3 Extraction of filters.

6.3.1.3.1 Low volume filter pack. After sampling the filter, papers were removed from the filter holders and placed in Millipore PetriSlides. The Fluoropore particulate filter and the sodium chloride impregnated Whatman 41 nitric acid filter were extracted using similar procedures. The filter was put in a beaker, 30-mL of hot deionized water added, and the beaker put in an ultrasonic cleaner for 15 minutes. The solution was decanted and the procedure repeated with another 30 mL portion of hot deionized water. The combined extracts were filtered through a 5 µm Mitex Filter (Millipore) and the final volume brought up to 100 mL with deionized water. The two glycerol-K_2CO_3 impregnated SO_2 filters were extracted together using a similar procedure except that 0.03% hydrogen peroxide was used as the extractant. The extracts were also diluted to 100 mL with 0.03% hydrogen peroxide.

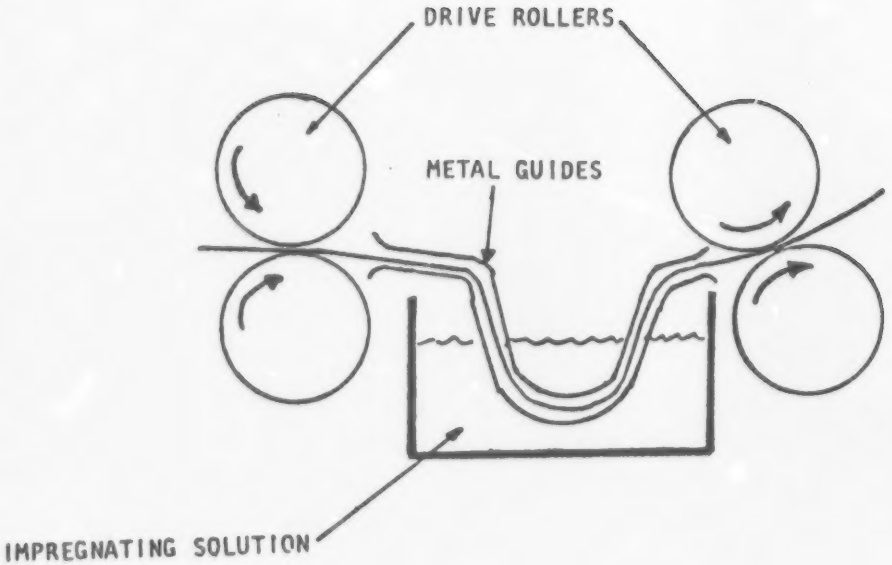


Figure 66. Schematic of photoprocessor used for impregnating filter papers.

6.3.1.3.2 High volume filter pack. The filters from the high volume filter pack were extracted using the same procedure described above with the following exceptions:

1. Particulate Filter. One-quarter of the filter was cut into small pieces and extracted using the standard procedure.
2. Nitric Acid Filter. One-quarter of the filter was cut into small pieces and extracted using the standard procedure. The filter extracts from the March samples were diluted to 100 mL. The filter extracts from the June samples were diluted to 200 mL.
3. Sulfur Dioxide Filter--One-quarter of each SO_2 filter was cut into small pieces and extracted with two 30 mL portions of hydrogen peroxide. The extracts were diluted to 220 mL with 0.1% H_2O_2.

6.3.1.4 Analysis of filters. The filter extracts were analyzed by ion chromatography (Dionex, Model 14) using a 3 mm x 150 mm pre-column, and a mixture of 0.0024 M sodium bicarbonate and 0.003 M sodium carbonate as the eluent. All columns were obtained from Dionex Corporation. Standards were prepared daily by dilution from 1000 ppm stock solutions. The stock solutions were prepared from analytical grade reagents. All dilutions of standards and eluents were made with deionized water (Millipore Milli-Q system). The analysis of the samples from the low volume filter pack, and the particulate filter and SO_2 filter from the high volume filter pack presented no problems. Difficulties were encountered in the analysis of the 100 mL extracts from the March samples of the sodium chloride impregnated nitric acid filters because of excessive overlap of the chloride and nitrate peaks. Sufficient resolution could be obtained when the samples were diluted. The 200 mL extracts from the June samples could be analysed without dilution.

6.3.1.5 References

Forrest, J., R.L. Tanner, D. Spandau, T. D'Ottavia, and L. Newman. 1979. "Determination of Atmospheric HNO_3 with NaCl-impregnated Filters at High Volume Flow Rates" in Current Methods to Measure Atmospheric Nitric Acid and Nitrate Artifacts, page 51. United States Environment Protection Agency, EPA-600/2-79-051.

Okita, T., S. Moremota, and S. Konns. 1976. "Measurement of Gaseous and Particulate Nitrates in the Atmosphere." Atmos. Environ. 10:1085.

Lusis, M.A., L.A. Barrie, H.A. Weibe, and K.G. Anlauf. 1977. "Development and Testing of a Filter Pack for Simultaneous Sampling of Gaseous and Particulate Sulfur Compounds in the Atmosphere." Atmospheric Environment Service, Internal Report ARQA 49-77.

6.3.2 Filterpack Data

All analysis results from filter samplings are presented in Table 50. Hi-vol samples were collected occasionally during March and June/July, and these results are tabulated directly after each filterpack result to permit comparison between the two sampling methods. Note that all data are in g total on each individual filter, where SO_2 is expressed as μg SO_4. Sampling time is in LST. Flow rate in litre. min^{-1} for filterpacks and $cft.min^{-1}$ for hi-vol samples.

6.4 HYDROCARBON SAMPLING

A cornerstone in current theories on excess ozone levels in a plume is the assumption that the dispersing plume entrains ambient air which contains sufficient hydrocarbons to provoke the necessary oxidation of NO to NO_2. A major part of the present study was directed towards establishing hdyrocarbon levels in the plumes from the oil sands plants. Reported emission data from the plants suggest negligible levels of hydrocarbons to be directly emitted by the chimneys.

6.4.1. Analytical Method

6.4.1.1. Aircraft sampling system. To obtain hydrocarbon data grab samples of air were collected while the airplane was actually flying

Table 50. Result of filter pack sampling.

Date	Origin	Dist. (mi)	Sampling time	Number of transv.	Flow Rate	Particulate Filter		HNO_3 Filter		SO_2 Filter	
						NO_3	SO_4	NO_3	SO_4	NO_3	SO_4
9 Jan	Suncor	8	1043-1103	7	19.5-19.0	4	4	-	4	T[a]	113
	Suncor	8	1105-1126	6	19.6-18.9	5	4	-	T	T	114
	Background	-	1132-1153	-	19.5-19.6	3	-	-	T	-	-
	Blank	-	- -	-	- -	3	-	-	-	T	-
	Syncrude	4	1755-1815	10	25.0-24.0	4	11	-	8	T	56
	Syncrude	6	1817-1838	11	24.0-23.5	5	12	-	4	T	52
	Background	-	1840-1900	-	24.5	8	4	-	T	T	6
	Blank	-	- -	-	- -	5	T	-	T	4	3
10 Jan	Syncrude	3	1242-1307	10	20.0- 1.5	T	7	0	6	T	9
	Background	-	1339-1354	-	15.6- 3.5	-	5	T	T	T	T
	Blank	-	- -	-	- -	4	3	-	8	3	-
11 Jan	Syncrude	2	1357-1419	14	21.0- 4.0	T	32	-	32	2	111
	Syncrude	8	1430-1502	15	6.8- 2.5	7	14	-	4	3	39
	Suncor	10	1505-1531	11	10.0- 9.8	4[b]	7	-	T	2	120
	Syncrude	15	1540-1615	13	10.5-10.5	7[b]	9	-	T	T	44
	Background	-	1646-1700	-	1.5- 1.5	ND[c]	ND	ND	ND	ND	ND
13 Jan	Syncrude	2	1106-1130	20	21.0-17.0	5	14	T	5	T	140
	Syncrude	10	1139-1211	11	18.0-18.5	6	14	-	4	2	87
	Syncrude	20	1216-1251	9	20.5-19.0	6	7	-	3	3	57
	Syncrude	30	1545-1618	7	19.0-19.5	6	9	-	4	-	54
	Background	-	1253-1308	-	18.0-19.0	-	8	-	4	T	8
	Blank	-	- -	-	- -	-	14	-	3	T	-

continued ...

Table 50. Continued.

Date	Origin	Dist. (mi)	Sampling time	Number of transv.	Flow Rate	Particulate Filter NO_3	Particulate Filter SO_4	HNO_3 Filter NO_3	HNO_3 Filter SO_4	SO_2 Filter NO_3	SO_2 Filter SO_4
18 Mar	Syncrude	2	1545-1651	30	19.0 -	5	20	T	3	3	164
	Suncor	2	1702-1735	30	19.1 -	6	7	T	T	6	209
	Background	2	1737-1746	-	18.8 -	8	3	-	T	4	180
19 Mar	Suncor	2	1728-1808	25	15.6-16.2	T	5	-	4	7	86
						T	14	-	T	7	129
	Suncor	11	1820-1916	25	15.2 -	6	4	-	4	8	98
						7	4	-	T	4	82
	Background	-	1918-1930	-	15.1 -	4	T	-	T	4	4
20 Mar	Syncrude	2	1112-1230	30	15.0 -	5	41	-	4	4	560
						7	37	T	3	8	578
					29.0 (HV)	27	1634	-	121	T	5480
	Suncor	2	1238-1410	30	14.6 -	5	26	-	5	7	1505
						5	25	T	T	7	1663
					29.0 (HV)	29	823	-	100	-	14188
	Background	-	1032-1104	-	14.8 -	5	T	-	T	4	T
	Blank	-	- -	-	- -	5	T	T	T	3	T
21 Mar	Syncrude	2	1225-1351	29	15.1 -	8	26	T	T	5	147
						5	27	T	T	7	322
					27.0-28.0 (HV)	10	325	-	T	-	1140
	Syncrude	8	1402-1531	t	14.9 -	-	14	T	T	6	370
						-	6	T	6	8	404
					27.0 (HV)	13	256	-	22	-	1318
	Syncrude	20	1715-1849	25	14.9 -	-	11	9	4	10	532
						4	12	-	-	10	532

continued ...

Table 50. Continued.

Date	Origin	Dist. (mi)	Sampling time	Number of transv.	Flow Rate	Particulate Filter		HNO_3 Filter		SO_2 Filter	
						NO_3	SO_4	NO_3	SO_4	NO_3	SO_4
24 Mar	Syncrude	2	1013-1130	50	15.0 -	4	10	T	10	10	866
						5	13	T	7	12	968
					29.0 (HV)	8	309	-	T	-	2598
	Suncor	2	1135-1315	60	15.0 -	-	4	T	3	7	422
						-	5	-	3	8	406
					29.0 (HV)	7	79	-	T	-	1352
	Background	-	936-1008	-	15.0 -	5	-	-	T	6	8
	Blank	-	- -	-	- -	T	T	T	5	6	8
25 Mar	Syncrude	2	1010-1110	25	13.8 -	-	11	-	3	6	408
						-	10	-	T	8	378
					29.0 (HV)	4	167	-	T	-	1246
	Syncrude	6	1314-1400	30	14.1 -	ND				10	180
						5	8	-	3	6	198
					29.0 (HV)	8	118	-	T	-	784
	Syncrude	25	1425-1520	t	14.2 -	-	8	4	T	9	230
						-	4	-	4	6	159
					29.0 (HV)	13	98	-	-	-	854
	Blank	-	- -	-	- -	T	T	T	T	6	6

continued ...

Table 50. Continued.

Date	Origin	Dist. (mi)	Sampling time	Number of transv.	Flow Rate	Particulate Filter NO_3	Particulate Filter SO_4	HNO_3 Filter NO_3	HNO_3 Filter SO_4	SO_2 Filter NO_3	SO_2 Filter SO_4
25 June	Syncrude	2	2000-2100		21.0 -	T	T	T	18	T	170
						5	T	6	7	7	165
					50(HV) -	T	50	T	130	T	1870
		8	2200-2350		21.0 -	5	4	6	15	T	365
						T	9	T	30	6	315
					50(HV) -	10	50	T	180	10	2490
28 June	Syncrude	1	1250-1345		21.0 -	6	5	T	9	T	290
						6	5	7	11	T	250
					50(HV)						
	Suncor	1	1420-1503		21.0 -	6	9	T	9	T	355
						5	8	T	16	T	400
					50(HV) -	20	50	T	70	T	1220
	Background		1508-1530		21 0 -	5	T	T	T	T	6
					50(HV) -	T	T	T	50	T	T
4 July	Syncrude	1	1010-1111	30	21.0 -	6	9	6	10	T	595
						6	9	5	14	T	800
					50(HV) -	20	110	-	200	T	5155
	Syncrude	5	1120-1225		21.0 -	7	12	5	14	6	378
						6	12	4	13	5	283
					50(HV) -	20	80	-	120	T	1580
	Background				21 0 -	T	T	T	T	5	10
					50(HV) -	T	10	-	20	T	T

continued ...

Table 50. Continued.

Date	Origin	Dist. (mi)	Sampling time	Number of transv.	Flow Rate	Particulate Filter		HNO_3 Filter		SO_2 Filter	
						NO_3	SO_4	NO_3	SO_4	NO_3	SO_4
5 July	Syncrude	35		c	18.0 -	7	10	10	21	T	1244
			515-645			6	9	12	18	T	1244
					50 (HV) -	20	110	-	100	30	11060
	Syncrude	5	650-755		18.0 -	T	T	9	20	T	339
						6	6	8	18	T	479
					50 (HV) -	20	80	-	80	T	5300
	Syncrude		800-835		18 0 -	6	6	10	30	T	690
		1			50 (HV) -	20	80	-	40	T	4750
7 July	Blank	-	- -	-	- -	5	6	T	T	4	T
	Syncrude	6	530-630	25	23.0 -	17	12	T	31	5	796
						18	10	6	22	5	613
					50 (HV) -	130	170	20	150	40	5660
	Syncrude	6	1040-1125	25	24.0 -	6	7	T	15	5	715
						6	7	7	12	T	564
					50 (HV) -	15	80	10	50	20	4120
	Syncrude	6	1445-1600	25	21.0 -	6	7	T	11	T	86
						5	6	T	11	T	111
					50 (HV) -	15	60	10	70	T	430
	Syncrude	6	1838-1928	25	24.0 -	6	6	T	7	T	31
						5	T	T	9	T	46
					51 (HV) -	10	30	-	40	T	110
	Syncrude	1	1130-1200	25	21.0 -	T	4	T	16	6	187
						5	4	T	27	5	417
					50 (HV) -	10	50	-	890	T	1110

continued ...

Table 50. Concluded.

Date	Origin	Dist. (mi)	Sampling time	Number of transv.	Flow Rate	Particulate Filter		HNO_3 Filter		SO_2 Filter	
						NO_3	SO_4	NO_3	SO_4	NO_3	SO_4
8 July	Syncrude	1.5	1130-1159	21	23.0 -	6	19	T	14	5	557
						5	21	T	12	7	570
					50.0(HV)	15	140	10	90	T	3120
	Syncrude	6	1045-1125	20	23.0	7	34	T	15	T	1064
						6	32	T	18	T	953
					50.0(HV)	15	210	-	100	T	6330
	Suncor	3.5	1530-1546		75.0(HV)	25	110	-	-	T	1100
	Suncor	8	1550-1610		75.0(HV)	15	50	-	-	T	690

within the plume, as indicated by the onboard monitors (SO_2 and NO_x). A ¼" stainless steel sampling line was employed which was located directly besides the Teflon sampling lines used for the filterpack collections. No isokinetic sampling tip was used. Inside the plane, a three-way valve was connected to the line, one side converting to an open (male Swagelock quick-connect fitting. Ten-litre Teflon bags, obtained from Environmental Measurements Inc., were used to collect the air samples. The bags were rapped in two black plastic bags to eliminate photolysis of the collected samples. Since the access part of these bags does not allow for a simple swagelock connection, small adaptors were constructed which were cemented to the post with a low vapour pressure epoxy. To this adaptor self-locking female swagelock quick connect fittings were attached.

The sampling procedure was as follows. The S.S. line was flushed and while flying within the plume, the sampling bag was connected. When the plane was out of the plume, the three-way valve was switched so that the ram air line kept being flushed, with the air now escaping to the cabin. By using this procedure only plume air was collected. Moreoever the use of quick connect closing connectors excluded contamination by cabin air.

Since the background air in the area is expected to be pristine, low ppb levels, if at all, hydrocarbons were expected, and it is important to place emphasis on the reliability of the sampling and analytical methods. The question of contamination by cabin air was further determined by carrying an empty bag, and a bag partly filled with prepurified (cylinder) N_2 in the plane on one flight. The empty bag was filled with some N_2 upon return in the field laboratory where the analysis was performed. Both samples did not show any increase in hydrocarbon levels over the impurities inherent to the analytical method. An evacuated glass bottle (L) was also carried, and opened in the cabin to specifically sample t in air. Analysis of this sample revealed the presence of ppm level ydrocarbons in the cabin air, that were apparently not collected in bag samples. The Tedlar bags

were flushed with prepurified N_2, and evacuated just prior to a flight in the field laboratory. It was determined that essentially no bag was really vacuum tight, but only bags that appeared to remain in a completely collapsed condition were used for sampling. After completion of each flight, the bags (normally filled close to capacity) were unloaded at the Mildred Lake air strip, and immediately transported to the field laboratory, whether analysis took place (the only exception here is the samples collected on 1980 May 11 - helicopter samples - and 1980 July 08; both these samples were at least two days old before analysis). Consequently, with the exception of the 1980 May 11 and 1980 July 08 samples, all analyses were completed well within a time period of 12 hours after collection of the sample. This procedure further enhances the reliability of the results, since there is some question of the integrity of prolonged storage of air samples in Tedlar bags.

6.4.1.2 Analysis procedure. The analysis of the grab samples for C_2-C_5 hydrocarbons closely followed procedures pioneered by groups at the EPA and Washington State University. A cryogenic trapping procedure was developed following these references, schematically shown in Figure 67. In this figure, V1-V_3 are three-part valves that all connect a functional part to a vacuum line or a section of the overall apparatus, or are closed. V_4 is a flow regulating needle valve, while V_5 is a six-part sampling valve. The sampling loop is either stainless steel or glass, filled with small glass beads, and while sampling, immersed in liquid argon (liquid argon was preferred over liquid oxygen mainly for safety of the procedure, its boiling point is only 2° lower than oxygen, and no problems of oxygen trapping on th sampling loop were ever experienced). Except for the lines going to the vacuum system, all connecting lines were made of 1/16" stainless steel tubing. The ballast tank actually consisted of two old lecture bottles, and the pressure gauge is a Matheson gauge, with a range of 0 to 760 torr, in 5 Torr divisions.

The sampling procedure was as follows. Valve V_1-V_3 and V_5 were first placed in the positions such that the whole system was

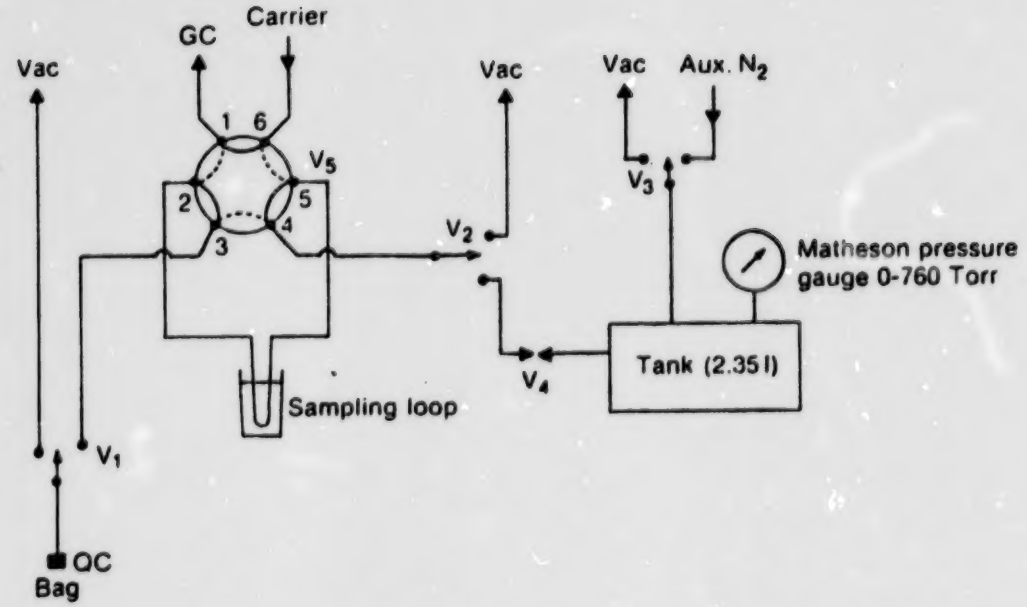


Figure 67. Cryogenic trapping/sampling procedure for hydrocarbon analysis.

evacuated. (Valve V_4 was never changed after its intiial setting.) In this situation the CG carrier gas passes through V_5 straight into the column. V_1 and V_2 were next closed, and the bag was connected at the quick fit connector QC. The sampling loop was then immersed in liquid argon, and the ballast tank was slightly pressurized to approximately 30 Torr with N_2 via valve V_3. After closing V_3 the initial pressure P_1 was determined in the tank. When the sampling loop appeared to be stabilized at liq. Ar temperature, values V_1 and V_2 were switched so that air was flowing via the sampling loopand needle valve V_4 towards the 2.35 l tank. V_4 was set so that the sampling rate was approximately 0.1 l/min. After enough air was sampled, valves V_1 and V_2 were again closed, and the final pressure in tank was read (P_2). Valve V_5 was then switched into the inject-position, and at the same time the dewar containing liquid argon around the sampling loop was replaced by a dewar containing boiling water. Although this injection procedure lead to some disruption in the carrier flow, it was determined after much experimentation that overall this injection procedure lead to the least problems with reproduceability and integration. Specifically, it was acceptable here since the retention time of the first peak of interest on the GC had a retention time of well over three minutes, and this allowed the baseline in the chromatogram to return almost completely to its original level. For consecutive analyses (most results reported here were based on the average of three GC-runs) the bags were not removed, but valve V_1 was kept closed while the system was evacuated via valves V_2 and V_3.

By knowing the volume of the tank, V_T, and determining the initial and final pressures P_1 and P_2, the amounts of air sampled, $V_T/(P_2 - P_1)$ moles at the temperature and atmospheric pressure in the laboratorium could be calculated. For a bag sample (constant pressure) this number was then divided by the barometric pressure yield immediately the volume of air sampled. This was not possible with samples in glass bottles (constant volume) and the proper corrections for temperature and pressure had to be applied.

The analysis itself was performed with a HP - 5830 gaschromatograph on a 16' x 3/16" copper column, packed with Durapak n-octane on porasil-C (DP). Although this column should be able to separate C_2 hydrocarbons, this appeared not to be possible with the described procedure and, starting with the March data, the samples were analysed separately on a 3' x ¼" copper column, packed with Porapak - N (PN), to establish the respective C_2 concentrations. The C_2 separation on Porapak-N was excellent, while separation up to C_6 on the Durapak column was very good indeed. C_6 compounds appeared to become overlapping and separation was less satisfactory. It was feasable that temperature programming might have improved the analysis. However invariably this seemed to result in baseline drifting which could not be easily compensated for with the 5830 gaschromatograph. In view of time constraints this was not further investigated, and all analyses were performed isothermally at 65°C and 50°C for DP and PN analyses respectively. Nitrogen carrier gas was employed at flow rates of 26 and 22 cc/min for DP and PN respectively, and a flame ionization detector was the hydrocarbon probe.

6.4.1.3 Calibration. Identification of the hydrocarbons was based on retention time analyses; authentic samples were used for calibration (see Table 51). From these calibration experiments it appeared that no problems should be encountered with paraffins up to C_6 and most olefins up to C_5. It can be seen that ambiguity exists for 1-butene and neopentane, which showed almost identical retention times. A few tests with a different column (Porapale-Q) indicated in all cases that the sample actually consisted of 1-butene and not neopentane. Although the levels, when observed, were always very low (< 1 ppb C), this is significant in that neopentane was actually expected (see main text).

Occasionally an analysis was studied over a much longer period to determine whether C_7 and C_8 paraffins, and aromatic hydrocarbons were present. (It was determined with authentic samples that the retention times for benzene and tolnene were approximately 180 and 230 minutes

Table 51. Retention time of hydrocarbons on Durapak (n-octane/porasil-C[a]) column.

Compound	Retention Time
ethane	3.60
ethylene	3.60
acetylene	4.20
propane	4.80
propene	5.80
i - butane	7.00
n - butane	7.90
neopentane	10.60
1 - butene	10.70
i - butene	12.30
butadiene 1, 3	12.70
t - 2 - butene	12.90
i - pentane	13.60
c - 2 butene	14.20
n - pentane	15.50
cyclopentane	17.50
1 - pentene	21.90
2 methyl pentane	29.90
2 - pentene	30.10
3 - methylpentane	30.60
methylcyclopentane	(32.50)
isoprene	33.60
n - hexane	34.50
2 - methyl - 2 - butene	35.20
cyclohexane	36.80
3 - methyl - hexane	68.50
benzene	187.00

[a] All times determined with ca. 2 mL authentic samples (except methyl cyclopentane, which is estimated). Accolades indicate that these compounds overlap in experimental mixtures and separation is not good. This causes problems for C_2 (separate column), neopentane/1-butene (see text), and C_6 (separate analysis intended but not performed). Column conditions as described in text for standard analysis procedure.

respectively on the Durapak column under the described conditions.) These tests appeared to indicate the presence of such compounds. Unfortunately it was impossible, due to time and personnel constraints, to determine C_6 - C_{10} hydrocarbons, and aromatics; such an analysis would have required a different column and a second GC oven in order to perform the analysis within 12 hours after collection. Alternate analyses methods were briefly explored but could not be instituted due to the time problems mentioned above and will not be described here.

To obtain quantitative analysis results calibration mixtures were prepared, consisting of small amounts of pure hydrocarbons in nitrogen. The preparation of these mixtures and calibration of the gas chromatograph were as as follows. Glass bottles of approximately 1 L volume were used, with carefully determined volume (see Figure 68). The bottles were evacuated on a high vacuum line, with the Teflon body of valve V_{11} replaced by a rubber septum. The stopcock from the Hivac line was then closed, and the cold finger immersed in liquid N_2. With a

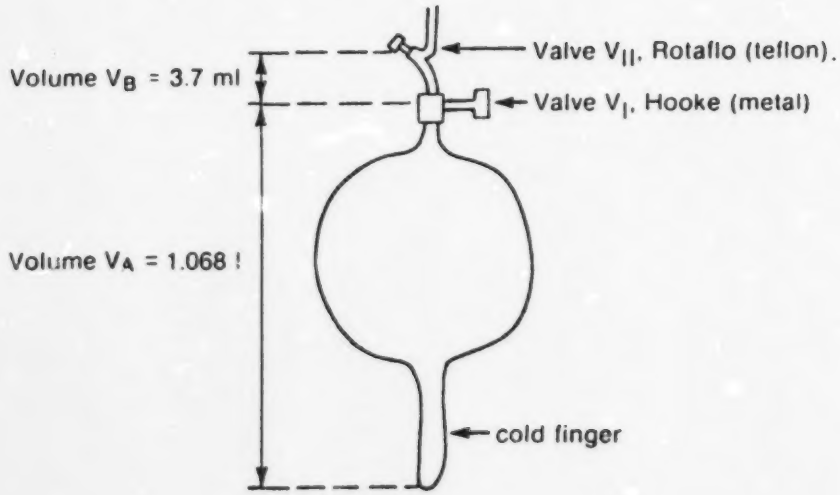


Figure 68. Glass bottle for calibration mixture.

gas tight microsyringe a few microlitres of pure compound was trapped on the cold finger. After all compounds were thus added, valve V_1 was closed, the bulk removed from the vacuum line, and the cold finger was warmed to room temperature. The bulb was pressured to atmospheric pressure with prepurified N_2, rushing from a cylinder through volume V_B, coming in at the main port of the bulb and departing through the seat of the Teflon valve (the septum was removed by the Teflon body not yet installed). Finally, convective mixing of the calibration mixtures was stimulated for at least 48 hours by heating one side of the glass bottle only.

The calibration procedure on the GC was as follows. The bulb containing the calibration mixture was connected to the air sampler, and the line from the sampling loop up to valve V_1 of the bulb was evacuated. Valve V_{11} was then closed, and V_1 opened so that the mixture expanded in the known volume between V_1 and V_{11}. Next V_1 was closed and V_{11} opened, and the total sample was collected on the sampling loop which was, as for an anlysis run, immersed in liquid argon, while valves V_2 and V_4 were in such a position that the N_2 from the calibration mixture flowed into the 2.35 L tank (which was evacuated for these calibration runs). By knowing the volumes of the bulb V_A, and the area between valves V_1 and V_{11}, B_B, the amount of hydrocarbon injected into the bulb, and the temperature and barometric pressure at the time of calibration mixture preparation, one knows exactly the amount of hydrocarbons injected by this procedure.

Since $V_B/V_A < 0.05$ the dilution of the calibration mixture after 50 injections is only of the order of 10% which is within the expected uncertainty of the overall analysis. Nevertheless this factor was always incorporated in the calibration runs. The calibration mixtures were also checked with direct syringe injections of pure compounds. The discrepancy between these two methods was approximately 5%, with the syringe suggesting that the calibration mixtures were slightly more dilute than calculated. Although this difference is small, it was assumed that the syringe injection was more accurate in that it involved less manipulation, and with ethylene as standard, the

calibration mixture concentrations were adjusted to the valves suggested by syringe injections.

A final question concerns the stability of the calibration mixtures with time. It was observed that the stability of paraffins was excellent, but the olefin concentration substantially decreased over a period of a few months. The cause of olefin decay at ppb levels in prepurified nitrogen, stored in a glass bottle, has not been established. One, rather unlikely, cause could be some slow reaction or the metal valve surface. Another exotic possibility is photolysis on the pyrex walls of the bulb.

6.4.1.4 Discussion of special problems. The methodology described here for hydrocarbon analysis of plume and ambient air appeared to be relatively simple and reliable. Some problems and suggestions warrant mentioning.

1. The major limitation of the work was the absence of data or C_6 - C_{10} hydrocarbons, in particular the aromatics. With the GC column employed, analysis for these compounds was not feasible. It was intended to explore the possiblity of doing this analysis at a later time by concentrating air samples on all-gas sampling loops. The glass sampling loops were then closed off with a torch while being under reduced pressure in liquid argon. Thus stored samples should remain unchanged for a long period of time, allowing analysis with a different column at a different location at a later time.
2. Since no natural gas is available at the Mildred Lake camp site, where the analyses were performed, a propane supply was routinely used in the field laboratorium for small glass blowing jobs. During the March study, a leak developd in the 6-port sampling valve which caused some room air to be trapped on the sampling loop. This problem was immediately apparent from the excessive propane peaks in almost all chromatograms obtained during

that study (these peaks moreover were irreproduceable in consecutive analyses of the same air sample). Hence, no propane data are reported for the March study. It should be emphasized that similar problems were not encountered during January or June/July. In particular the abnormally high propane mixing ratios found in 1980 July 04 air samples were reproduceable and appear to be real.

3. A rigorous error analysis was not performed for the data reported here. From a cursory review of all procedures involved, the accuracy of the numbers reported was estimated to be the ca. 25%, mainly due to uncertainties in the calibration procedures. The precision of the data was generally better than 15% for mixing ratios above 1 ppb C.

6.4.2 Hydrocarbon Data

The analyses of the bag samples for light hydrocarbons are presented in Tables 52 to 67. Note that all data are in ppb C by volume.

Table 52. Hydrocarbon data of samples collected on 1980 January 09.

	Mixing Ratio in ppb C							
Location	1	2	3	4	5	6	7	8
ethane	22.8							
ethylene								
acetylene	10.2							
propane	14.4							
propene	T							
i-butane	2.9							
n-butane	4.3							
1-butene								
i-butene								
t-2-butene								
i-pentane	T							
n-pentane	T							
cyclopentane								
1-pentene								
2-m-pentane								
3-m-pentane								
methylcyclopentane								
n-hexane								
cyclohaxane								

Number	Location	Sampling Time (MST)	Comments
1	Syncrude; 4 mL	1740-1750	

- Trace

Table 53. Hydrocarbon data of samples collected on 1980 January 10.

	Mixing Ratio in ppb C							
Location	1	2	3	4	5	6	7	8
ethane	25.3	42.	65.	9.2	1.9			
ethylene								
acetylene	5.7	7.3	7.6	1.2	--			
propane	89.5	322.	1150.	4.4	3.0			
propene	4.9	17.4	28.2	T	--			
i-butane	12.7	8.5	10.3	1.7	0.9			
n-butane	16.1	17.5	16.4	2.8	--			
1-butene	T	5.8	6.2	--	--			
i-butene	--	--	--	--	--			
t-2-butene	--	--	--	--	--			
i-pentane		13.6	11.5	--	--			
n-pentane	n.a.	8.7	8.0	--	--			
cyclopentane	--	--	--	--	--			
1-pentene	--	--	--	--	--			
2-m-pentane				--	--			
3-m-pentane				--	--			
methylcyclopentane	n.a.	n.a.	n.a.	--	--			
n-hexane				--	--			
cyclohaxane				--	--			

Number	Location	Sampling Time (MST)	Comments
1	Syncrude; 3 mi	1302-1307	Sample from ice fog. Numbers 1, 2, and 3 are results of consecutive analysis of the same ice fog air sample.
2			
3			
4	Background	1343-1347	Upwind; some ice fog still apparent here.
5	Blank		Empty bag, carried in plane but not filled. In lab later filled with cylinder N_2.

Table 54. Hydrocarbon data of samples collected on 1980 January 11.

	Mixing Ratio in ppb C							
Location	1	2	3	G-1	5	6	7	8
ethane	22.4	19.0	10.1	16.3				
ethylene								
acetylene	5.4	4.5	1.4	5.6				
propane	7.1	6.0	5.2	15.4				
propene	T	--	--	1.6				
i-butane	1.3	1.3	1.5	3.6				
n-butane	2.8	2.8	4.0	13.6				
1-butene	T	--	T	4.0				
i-butene	--	--	--	--				
t-2-butene	--	--	--	--				
i-pentane	1.4	1.7	2.7	9.5				
n-pentane	1.7	2.1	3.1	16.7				
cyclopentane	--	--	--	10.4				
1-pentene	--	--	--	--				
2-m-pentane		--	--					
3-m-pentane		--	--					
methylcyclopentane	T	--	--	n.a.				
n-hexane		--	--					
cyclohaxane		--	--					

Number	Location	Sampling Time (MST)	Comments
1	Syncrude, 2 mi	1400-1410	Only in plume collections.
2	Syncrude, 8 mi	1430-1445	
3	Syncrude, 15 mi	1540-1544	
G-1	Mildred Lake Camp	1645	Glass bottle, evacuated and opened. Wind blowing from Syncrude site to camp (very bad smell at campsite).

Table 55. Hydrocarbon data of samples collected on 1980 January 13.

	Mixing Ratio in ppb C							
Location	1	2	3	4	5	G-1	G-2	8
ethane	34.1	26.1	23.9	21.4		23.2	14.7	16.4
ethylene								
acetylene	7.3	4.3	4.2	4.0		6.7	3.1	2.2
propane	22.0	21.3	18.1	17.0		25.4	15.1	20.9
propene	T	--	--	--		2.3	--	T
i-butane	5.0	4.6	4.7	3.9		3.6	8.3	4.0
n-butane	11.4	11.3	10.3	11.1		17.2	8.3	11.5
1-butene	T	--	--	--		--	--	T
i-butene	--	--	--	--		--	--	--
t-2-butene	--	--	--	--		--	--	--
i-pentane	4.8	4.8	4.6	6.3		11.3	7.0	5.7
n-pentane	4.6	4.0	3.1	6.6		9.1	5.2	7.0
cyclopentane	T	--	--	--		--	--	--
1-pentene								
2-m-pentane								
3-m-pentane								
methylcyclopentane	n.a.							
n-hexane								
cyclohaxane								

Number	Location	Sampling Time (MST)	Comments
1	Syncrude, 2 mi	1100-1130	In plume.
2	Syncrude, 10 mi	1139-1145	
3	Syncrude, 20 mi	1216-1220	
4	Syncrude, 30 mi	155-1610	
G-1	1 mi from plant	ca. 1115	Ground level collections in evacuated glass bottles.
G-2	5 mi from plant	ca. 1130	
G-3	9 mi from plant	ca. 1230	

Table 56. Hydrocarbon data of samples collected on 1980 March 18.

	Mixing Ratio in ppb C							
Location	1	2	3	4	5	6	7	8
ethane	10.2	12.0						
ethylene	1.6	1.2						
acetylene	2.6	3.0						
propane	ND[a]	ND						
propene	T	T						
i-butane	1.4	1.8						
n-butane	3.3	3.8						
1-butene	--	--						
i-butene	--	--						
t-2-butene	--	--						
i-pentane	00	T						
n-pentane								
cyclopentane								
1-pentene								
2-m-pentane								
3-m-pentane								
methylcyclopentane								
n-hexane								
cyclohaxane								

Number	Location	Sampling Time (MST)	Comments
1	Syncrude, 2 mi	1610-1615	
2	Syncrude, 2 mi	1705-1710	Plume probably mixed with Syncrude plume.

[a] not determined

Table 57. Hydrocarbon data of samples collected on 1980 March 19.

	Mixing Ratio in ppb C							
Location	1	2	3	4	5	6	7	8
ethane	17.7	14.1	9.4					
ethylene								
acetylene	1.4	1.0	0.8					
propane	ND[a]	ND	ND					
propene	1.3	T	--					
i-butane	3.9	1.5	1.3					
n-butane	1.8	4.6	3.0					
1-butene	4.1	T	--					
i-butene	1.5	T	T					
t-2-butene	T	T	--					
i-pentane	11.1	1.8	T					
n-pentane	23.4	2.4	T					
cyclopentane	4.4	--	--					
1-pentene	5.5	--	--					
2-m-pentane	27.1	--	--					
3-m-pentane								
methyl-cyclopentane	33.5	--	--					
n-hexane	T	--	--					
cyclohaxane								

Number	Location	Sampling Time (MST)	Comments
1	Syncrude, 2 mi	1728-1808	
2	Syncrude, 2 mi	1820-1916	
3	Background	1925	ca 10 mi downwind of Suncor, but parallel to plume (SO_2 = NO_x = 0, according to on board detectors).

[a] not determined

Table 58. Hydrocarbon data of samples collected on 1980 March 20.

	Mixing Ratio in ppb C							
Location	1	2	3	4	5	6	7	8
ethane	11.0	9.6	8.3					
ethylene	5.9	1.3	T					
acetylene	3.6	1.6	1.1					
propane	n.d.	n.d.	n.d.					
propene	1.3	0.3	T					
i-butane	3.8	2.5	1.6					
n-butane	7.8	8.6	2.9					
1-butene	0.7	0.8	T					
i-butene	0.5	1.0	T					
t-2-butene	T	T	--					
i-pentane	4.8	5.8	0.9					
n-pentane	7.1	6.6	0.9					
cyclopentane	2.8	T						
1-pentene	--	T	--					
2-m-pentane 3-m-pentane	14.4	T	--					
methyl- cyclopentane	15.6	--	--					
n-hexane	22.8	T	--					
cyclohaxane	5.4	--	--					
paraffins[a]	95.5	33.1	14.6					
olefins[b]	2.5	2.1	T					

Number	Location	Sampling Time (MST)	Comments
1	Syncrude, 2 mi	1130-1140	
2	Suncor, 2 mi	1245-1255	Could be mixed with Syncrude plume.
3	Background	1032-1104	20 mi upwind..

excl. C_3H_8
excel. C_2H_4

Table 59. Hydrocarbon data of samples collected on 1980 March 21.

	Mixing Ratio in ppb C							
Location	1	2	3	4	5	6	7	8
ethane	13.7	8.7	8.2					
ethylene	4.3	1.4	0.7					
acetylene	2.6	2.2	1.9					
propane	ND	ND	ND					
propene	2.1	0.4	T					
i-butane	3.3	1.3	1.3					
n-butane	9.2	3.7	3.1					
1-butene	0.9	T	T					
i-butene	0.9	T	T					
t-2-butene	T	--	--					
i-pentane	5.0	1.7	1.1					
n-pentane	8.3	2.8	1.7					
cyclopentane	3.4	2.1	0.6					
1-pentene	--	--	--					
2-m-pentane								
3-m-pentane	20.0	5.7	2.9					
methyl-cyclopentane	23.3	5.3	3.5					
n-hexane	31.9							
cyclohaxane	8.0	10.5	6.7					
paraffins[a]	126.1	41.8	29.1					
olefins[b]	3.9	0.4	T					

Number	Location	Sampling Time (MST)	Comments
1	Syncrude, 2 mi	1245	
2	Syncrude, 8 mi	1445	Could be mixed with Suncor.
3	Syncrude, 20 mi	1800	Probably mixed with Suncor.

[a] excl. C_3H_8
[b] excel. C_2H_4

Table 60. Hydrocarbon data of samples collected on 1980 March 24.

	Mixing Ratio in ppb C							
Location	1	2	3	4	5	6	7	8
ethane	9.4	8.6	7.7					
ethylene	3.2	0.5	T					
acetylene	2.4	1.8	1.6					
propane	ND	ND	ND					
propene	0.7	0.2	--					
i-butane	1.6	1.7	1.0					
n-butane	5.0	1.7	1.0					
1-butene	T	0.9	--					
i-butene	T	0.5	--					
t-2-butene	--	--	--					
i-pentane	2.6	4.5	1.5					
n-pentane	4.6	8.2						
cyclopentane	1.5	0.7	--					
1-pentene	--	1.7	--					
2-m-pentane	5.8	6.3	--					
3-m-pentane								
methyl-cyclopentane	6.6	--	--					
n-hexane								
cyclohaxane	11.9	3.5	--					
paraffins[a]	49.0	40.2	12.6					
olefins[b]	0.7	3.3	T					

Number	Location	Sampling Time (MST)	Comments
1	Syncrude, 2 mi	1015	
2	Syncrude, 2 mi	1145	20 mi upwind

[a] excl. C_3H_6
[b] excel. C_2H_4

Table 61. Hydrocarbon data of samples collected on 1980 March 25

	Mixing Ratio in ppb C							
Location	1	2	3	4	5	6	7	G-1
ethane	7.9	7.8	7.7	15.7	8.5	8.1	7.6	10.3
ethylene	0.4	0.2	0.3	13.9	1.0	0.9	0.5	15.7
acetylene	1.0	1.1	1.1	5.5	1.4	1.0	0.9	1.7
propane	ND	ND	ND	17.5	ND	ND	ND	ND
propene	T	--	--	7.2	T	T	T	0.4
i-butane	0.9	1.1	1.0	5.8	1.8	1.8	1.2	0.7
n-butane	1.8	2.3	2.2	25.8	4.0	4.8	3.9	2.5
1-butene	--	--	--	7.6	T	T	T	--
i-butene	--	--	--	3.5	T	T	T	--
t-2-butene	--	--	--	T	T	--	--	--
i-pentane		--	T	22.3	1.6	2.4	1.9	T
n-pentane	0.5	--	0.5	41.1	2.8	2.7	ND	T
cyclopentane	--	--	--	23.6	T	--	ND	--
1-pentene	--	--	--	7.6	--	--	--	--
2-m-pentane 3-m-pentane	--	--	--		2.7	7.8		--
methyl- cyclopentane	--	--	--	ND[a]			13.2	--
n-hexane	--	--	--		10.7	11.8		--
cyclohaxane	--	--	--					--
paraffins[a]	11.1	11.2	11.4					
olefins[b]	T	--	--					

Number	Location	Sampling Time (MST)	Comments
1	Background, 3000' MSL	0915	
2	Same, 8000' MSL	0920	
3	over Syncrude, 8000' MSL	0955	
4	same, 1300' MSL	1000	Directly over mine.
5	Syncrude plume, 2 mi	1015	
6	Syncrude plume, 6 mi	1330	
7	Syncrude plume, 25 mi	1445	Could be mixed with Suncor.
G-1	0.5 mi north of Fort MacKay	0930	Ground level, glass bottle sample.

[a] Large amounts impossible to quantify with the GC column used.
[b] Excl. C_3H_8
[c] Excl. C_2H_4

Table 62. Hydrocarbon data of samples collected on 1980 May 11.

	Mixing Ratio in ppb C							
Location	1	2	3	4	5	6	7	8
ethane	7.6	6.3	10.3	5.9				
ethylene	2.4	T	0.6	T				
acetylene	1.7	1.3	1.0	1.1				
propane	5.9	2.0	9.4	2.0				
propene	1.6	0.5	1.2	0.3				
i-butane	2.0	0.4	2.1	0.3				
n-butane	8.1	1.0	9.8	0.6				
1-butene	1.5	0.3	1.9	--				
i-butene	2.0	0.3	3.2	--				
t-2-butene	0.6	--		--				
i-pentane	3.6	0.5	8.1	0.2				
n-pentane	8.5	1.8	21.5	0.9				
cyclopentane	1.5	--	1.8	T				
1-pentene	1.7	--	4.3	--				
2-m-pentane	10.3	T	12.7	--				
3-m-pentane		0.5	4.7	--				
methyl-cyclopentane	8.6	T	5.6	--				
n-hexane	13.9	3.9	17.8	--				
cyclohaxane	17.4	9.0	19.5	--				
paraffins[a]	87.4	25.4	123.3	9.6				
olefins[b]	11.	1.1	10.6	0.3				

Number	Location	Sampling Time (MST)	Comments
1	Syncrude, over stack	1500-1600	These samples taken by helicopter sampling.
2	Syncrude mine	1500-1600	Stack samples directly over stack.
3	Suncor, over stack	1500-1600	Syncrude mine sample low over the open pit, but not downwind form the stack.
4	Background	1500-1600	

[a] Excl. C_2H_4

Table 63. Hydrocarbon data of samples collected on 1980 June 28.

	Mixing Ratio in ppb C							
Location	1	2	3	4	5	6	7	8
ethane	6.2	5.9	4.5					
ethylene	14.6	3.0	2.6					
acetylene	10.2	0.5	T					
propane	6.3	5.0	ND					
propene	0.7	0.6	T					
i-butane	0.7	1.8	T					
n-butane	1.7	10.5	0.5					
1-butene	1.0	2.6	T					
i-butene	T	1.8	T					
t-2-butene	T	1.2	T					
i-pentane	1.3	8.6	T					
n-pentane	2.9	16.8	T					
cyclopentane	0.7	2.8	--					
1-pentene	2.1		--					
2-m-pentane 3-m-pentane	ND[a]		--					
methyl-cyclopentane	20.4	ND[b]	13.0					
n-hexane	ND		--					
cyclohaxane								
paraffins[a]	19.7	51.4	5.0					
olefins[b]	3.8	6.2	T					

Number	Location	Sampling Time (MDT)	Comments
1	Syncrude, 1.5 mi	1300	
2	Suncor, 1.5 mi	1430	
3	Background		

[a] ND - not determined
[b] See text. Fair amount of seveal unidentified peaks

Table 64. Hydrocarbon data of samples collected on 1980 July 04.

	Mixing Ratio in ppb C							
Location	1	2	3	4	5	6	7	8
ethane	8.5	6.5	5.2					
ethylene	6.1	5.0	1.2					
acetylene	2.1	1.1	0.4					
propane	162.0	53.8	31.7					
propene	2.5	1.2	T					
i-butane	3.4	1.8	0.7					
n-butane	8.6	5.6	1.2					
1-butene	1.2	0.9	--					
i-butene	0.8	0.8	T					
t-2-butene	T	T	--					
i-pentane	4.9	3.5	T					
n-pentane	9.5	7.2	T					
cyclopentane	2.7	3.0	--					
1-pentene	T	T	--					
2-m-pentane			--					
3-m-pentane			--					
methyl-cyclopentane	98.6	ND	10.7					
n-hexane			--					
cyclohaxane			--					
paraffins[a]	199.6	81.4	38.8					
olefins[b]	4.5	2.9	T					

Number	Location	Sampling Time (MDT)	Comments
1	Syncrude, 1 mi	1030	Very high C_3H_8 levels were reproduceable in all samples.
2	Syncrude, 5 mi	1150	
3	Background	1250	

Table 65. Hydrocarbon data of samples collected on 1980 July 05.

	Mixing Ratio in ppb C							
Location	1	2	3	4	5	6	7	8
ethane	5.8	5.9	3.6					
ethylene	14.4	9.5	23.1					
acetylene	20.7	10.3	22.9					
propane	7.4	7.7	8.0					
propene	T	0.7	0.7					
i-butane	3.9	2.3	2.6					
n-butane	2.4	2.5	3.1					
1-butene	--	T	T					
i-butene	--	T	T					
t-2-butene	--	T	T					
i-pentane	2.5	1.8	1.9					
n-pentane	1.3	1.6	2.9					
cyclopentane	--	--	--					
1-pentene	--	--	--					
2-m-pentane	--	--	6.0					
3-m-pentane	--	--						
methyl-cyclopentane	1.1	4.7	6.1					
n-hexane	--	ND[a]	10.8					
cyclohaxane	--							
paraffins[a]	20.5	26.5	45.0					
olefins[b]	T	0.7	0.7					

Number	Location	Sampling Time (MDT)	Comments
1	Syncrude, 35 mi	0600	
2	Syncrude, 5 mi	0700	
3	Syncrude, 1 mi	0800	

[a] Excl. C_2H_4

Table 66. Hydrocarbon data of samples collected on 1980 July 07.

	Mixing Ratio in ppb C							
Location	1	2	3	4	5	6	7	8
ethane	18.3	4.5	5.7	5.3	8.1	6.1	7.8	7.0
ethylene	25.9	7.3	1.6	1.6	10.9	6.0	3.4	6.9
acetylene	10.9	9.3	0.7	0.6	1.6	2.5	1.6	1.2
propane	6.4	2.4	3.0	2.6	2.5	1.7	6.0	5.1
propene	6.1	T	T	0.4	1.6	1.2	2.0	T
i-butane	0.4	T	1.7	0.4	T	T	1.0	0.7
n-butane	2.3	1.0	2.1	2.0	1.3	0.4	5.3	2.3
1-butene	1.3	--	T	T	T	--	0.9	T
i-butene	0.8	--	T	T	T	--	0.8	T
t-2-butene	1.1	--	T	T	T	--	T	--
i-pentane	1.1	T	T	0.7	0.5	--	2.6	1.2
n-pentane	0.8	0.4	1.2	2.3	1.4	--	5.2	2.1
cyclopentane	--	--	--	T	--	--	2.6	--
1-pentene	T	0.8	--	T	--	--	1.8	T
2-m-pentane	T	--	--	2.8	--	--	7.3	T
3-m-pentane	--	--	--		--	--		
methyl-cyclopentane	12.3	2.6	24.5	28.2	3.0	2.4	34.6	12.8
n-hexane	ND	ND	T	10.1	--	--	5.3	--
cyclohaxane								
paraffins[a]	29.3[a]	8.3[a]	38.2	53.7	16.8	10.6	92.0	31.2
olefins[b]	9.3	0.8	T	0.4	1.6	1.2	5.5	T

Number	Location	Sampling Time (MDT)	Comments
1	Syncrude, 6 mi	0600	
2	Syncrude, 6 mi	1100	
3	Syncrude, 6 mi	1500	
4	Syncrude, 6 mi	1830	
5	Background	0730	
6	Syncrude, 25 mi	0650	
7	Syncrude, 1 mi	1200	
8	Syncrude, 20 mi	1430	A^+ position where excess ozone was apparent.

[a] C_2H_5

Table 67. Hydrocarbon data of samples collected on 1980 July 08.

	Mixing Ratio in ppb C							
Location	1	2	3	4	5	6	7	8
ethane	10.8	6.8	4.3	5.4				
ethylene	27.2	7.3	1.7	2.0				
acetylene	40.3	11.0	1.2	2.6				
propane	6.8	4.9	2.2	8.8				
propene	1.7	1.1	0.1	0.2				
i-butane	0.8	0.7	T	0.8				
n-butane	4.1	2.6	1.7	3.2				
1-butene	0.5	0.6	T	0.3				
i-butene	1.2	0.3	T	0.3				
t-2-butene	T	T	--	T				
i-pentane	2.2	0.9	T	1.6				
n-pentane	4.5	2.5	1.3	4.0				
cyclopentane	1.1	T	--	--				
1-pentene	T	--	--	--				
2-m-pentane 3-m-pentane	4.5	2.0	T	1.8				
methyl- cyclopentane	9.7		T	10.2				
n-hexane cyclohexane	10.8	9.1	T	ND[a]				
paraffins[a]	55.3	29.5	9.5	37.8				
olefins[b]	3.4	2.0	0.1	0.8				

Number	Location	Sampling Time (MDT)	Comments
1	Syncrude, 6 mi	1100	
2	Syncrude, 1.5 mi	1145	
3	Syncrude, 15 mi	1400	Sampled at location where excess ozone was observed (numbers 3 and 4).
4	Suncor, 8 mi	1530	All these samples analyzed in Edmonton on 11-07-80.

[a] Excl. C_2H_4

6.5 IN SITU MONITORING DATA

Direct monitors for NO, NO_x, O_3, and SO_2 were carried on board of the aircraft, as discussed in section 6.1. All information thus obtained has been stored on magnetic tape. The organization of this data tape is presented in Table 68.

It has been discussed earlier that, during the January and March field trips, the on board Data Acquisition System did not function properly, and all data from in situ monitors have therefore digitized from backup stripchart recorder traces. Although the DAS appeared to function properly during the summer field trip, the actual information stored on magnetic tape is of poor quality. Stripchart recorder traces for SO_2 and O_3 for the last two days of operation were available (not digitized); these data were used for determination of ozone bulge occurrence.

Table 68. Data tape.

File No.	Block Count	Tapelth (Feet)	Block Av.	Lth Av.	Date	Time First Report (MST/MDT)
1	5	.70	3656	3700	09-01-80	1043
2	9	.98	3519	3700	09-01-80	1740
3	5	.68	3567	3700	10-01-80	1242
4	14	1.36	3610	3700	11-01-80	1357
5	13	1.29	3629	3700	13-01-80	1106
6	3	.53	3416	3700	13-01-80	1545
7	12	1.22	3669	3700	18-03-80	1545
8	12	1.20	3558	3700	19-03-80	1728
9	20	1.82	3645	3700	20-03-80	1112
10	22	1.94	3535	3700	21-03-80	1225
11	12	1.19	3478	3700	21-03-80	1715
12	10	1.04	3426	3700	24-03-80	1013
13	40	6.69	9938	10000	25-06-80	2134
14	29	4.92	9914	10000	27-06-80	2010
15	61	10.02	9918	10000	28-06-80	1230
16	53	8.73	9906	10000	04-07-80	1020
17	65	10.72	10000	10000	05-07-80	509
18	36	6.03	9897	10000	07-07-80	526
19	25	4.30	9952	10000	07-07-80	1037
20	34	5.74	9965	10000	07-07-80	1345
21	25	4.32	10000	10000	07-07-80	1442
22	28	4.73	9821	10000	07-07-80	1805
23	32	5.35	9806	10000	08-07-80	1035
24	60	9.89	9958	10000	08-07-80	1315
25	4	.57	2886	3700	11-01-80	1505
26	5	.65	3027	3700	11-01-80	1540
27	8	.88	3330	3700	25-03-80	1010
28	13	1.26	3455	3700	25-03-80	1314

Total Tape Length = 98.76 feet
Location: University of Alberta Computer Centre, Tape No. 006889
General Information: None-labelled, 9-track, 6250 BPI, 28 files

Record Structure: files 1 to 12, 25-28: format I3, I6, 4(IX, I2, I4)
where column 1-3: Julian date
column 4-9: local time (MST) in HHMMSS
column 11-12, 18-19, 25-26, 32-33: identifier1
1 -= NO_x, 2 = NO_3 = O_3, 4 = SO_2
column 13-16, 20-23, 27-30, 34-37: data value in ppb
files 13 to 24: format I3, I6, 13 (IX, I2, I4)
where column 1-3: Julian date
column 4-9: local time (MDT) in HHMMSS
column 11-12, etc.: identifier
column 13-16: data value in appropriate units

Table 68. Concluded.

(1)	blank		
(2)	temperature	20.408 x (value) - 51, °C	
(3)	dewpoint	21 x (value) - 53, °C	
(4)	airspeed	-60.61 x (value)+ 61.5, knots	
(5)	altitude	-4444.4 x (value) - 805	
(6)	NO_x	0 to 1000*, ppb	
(7)	NO	0 to 1000*, ppb	
(8)	O_3	0 to 1000*, ppb	
(9)	SO_2	0 to 1000*, ppb	
(10)	differential pressure (hi-vol)		0.1 x (value)
(11)	differential pressure		0.1 x (value)
(12)	blank		
(13)	filterpack flowrate		0.1 x (value, $l\ min^{-1}$)

* Actual full scale reading varies; appropriate correction factors are reported in the corresponding tables in Section 6.2.

6.6 AUXILLIARY DATA

6.6.1 Stack Monitoring Data from Syncrude Ltd

In Tables 69 to 83, the daily stack monitoring reports of Syncrude Canada Ltd., for the days that field measurements were made, are presented. For several of these periods, data are missing due to problems with the plant computer, but in general, one can obtain insight of the average emission levels from these tables. Note that the emission rate is reported in Long Tonnes (LT) per hour (1 LT = 1.016×10^3 kg).

Table 69. Report for the 24 h ending 0700, 1980 January 09; o.s h. clock averages.

Time (MST)	Temperature (°C)	SO_2 Concentration (ppm)	SO_2 Rate (LT/h)
0731	216.6	1298:	2.05
0801	216.9	1189:	1.86
0831	217.5	1050:	1.68
0901	217.9		
0931	218.4		
1001	218.7		
1031	219.0		
1101	219.2		
1131	218.8		
1201	217.8		
1231	217.8		
1301	217.9		
1331	217.9		
1401	217.5		
1431	217.1		
1501	216.5		
1531	216.6		
1601	215.4		
1631	215.9		
1701	215.9		
1731	216.9		
1801	216.7		
1831	216.7		
1901			
1931			
2001			
2031			
2101			
2131			
2201			
2231			
2301			
2331			
0001			
0031			
0101			
0131			
0201			
0231			
0301			
0331			
0401			

continued ...

Table 69. Concluded.

Time (MST)	Temperature (°C)	SO_2 Concentration (ppm)	SO_2 Rate (LT/h)
0431	213:2	1215:	1:94
0501	212:7	1189:	1:90
0531	212:1	1195:	1:90
0601	211:1	1135:	1:90
0631	216:1	1154:	1:98
0701	215:8	1177:	1:97

Table 70. Report for the 24 h ending 9700, 1980 January 13; o.s.h. clock averages.

Time (MST)	Temperature (°C)	SO_2 Concentration (ppm)	SO_2 Rate (LT/h)
0731	215.4	1160.	1.95
0801	214.6	1149.	1.93
0831	215.2	1172.	1.91
0901	217.8	1170.	1.88
0931	216.5	1108.	1.90
----------DATA MISSING----------			
1101	214.5	1096.	2.00
1131	215.0	1094.	2.00
1201	214.6	1058.	1.96
1231	214.3	1109.	1.79
1301	213.5	1152.	1.81
----------DATA MISSING----------			
1401	213.1	1632.	2.49
1431	211.8	1037.	1.64
1501	210.3	1306.	1.98
1531	210.8	1167.	2.00
1601	212.5	1113.	1.90
1631	213.6	1072.	1.89
----------DATA MISSING----------			
0801	206.6	970.	1.55
0831	207.7	951.	1.48
0901	206.5	894.	1.40
0931	208.6	892.	1.46
1001	211.6	848.	1.39
1031	210.8	922.	1.50
1101	208.8	913.	1.55
1131	206.6	1009.	1.79
1201	207.5	923.	1.51
1231	207.9	840.	1.40
----------DATA MISSING----------			
2331	207.7	1208.	2.05
0001	207.7	1132.	1.93
0031	207.4	1090.	1.90
0101	207.1	1022.	1.94
0131	207.4	1055.	1.95
0201	208.8	1074.	1.96
0231	209.0	1033.	1.94
0301	208.4	1032.	1.91
0331	206.5	1090.	2.01
0401	207.3	1022.	2.02
0431	209.8	989.	2.04

continued ...

Table 70. Concluded.

0501	211.6	958.	2.04
0531	209.3	1014.	1.96
0601	208.6	1055.	2.01
0631	207.4	1012.	1.91
0701	207.1	1024.	2.10

Table 71. Report for the 24 h ending 0700, 1980 January 14; o.s.h. clock averages.

Time (MST)	Temperature (°C)	SO_2 Concentration (ppm)	SO_2 Rate (LT/h)
0731	209.0	953:	2.03
0801	209.3	946:	2.00
0831	210.6	939:	2.04
0901	212.4	894:	1.94
0931	212.9	856:	1.89
1001	210.9	741:	1.62
1031	210.7	811:	1.72
1101	211.3	805:	1.68
1131	209.7	805:	1.66
1201	211.4	786:	1.64
1231	210.4	822:	1.75
1301	211.4	802:	1.67
1331	208.7	876.	1.68
1401	207.9	901:	1.70
1431	208.6	812:	1.51
1501	207.1	782:	1.53
1531	210.7	756:	1.59
1601	210.7	758:	1.57
1631	210.8	718:	1.52
1701	212.1	754:	1.55
1731	211.5	827:	1.76
1801	211.7	826:	1.76
1831	211.3	904:	1.93
1901	213.4	884:	1.88
1931	211.6	907:	1.89
2001	210.7	888:	1.88
2031	211.8	909:	1.96
2101	212.6	906:	1.99
2131	213.7	947:	2.05
2201	211.5	949:	2.00
2231	211.3	932:	2.01
2301	212.5	928:	1.97
2331	211.8	978:	2.04
0001	211.8	1019:	1.98
0031	210.4	1046:	1.97
0101	211.2	1021:	1.95
0131	209.9	1034:	1.94
0201	209.0	1034:	1.91
0231	207.3	1068:	1.97
0301	207.0	1029:	1.88
0331	207.3	1063:	1.93

continued ...

Table 71. Concluded.

0401	207.5	976:	1.81
0431	206.6	975:	1.78
0501	207.1	887:	1.58
0531	205.4	897:	1.62
0601	206.2	1005:	1.79
0631	207.0	983:	1.75
0701	207.9	956:	1.76

Table 72. Report for the 24 h ending 0700, 1980 March 19; o.s.h. clock averages.

Time (MST)	Temperature (°C)	SO_2 Concentration (ppm)	SO_2 Rate (LT/h)
----------DATA MISSING----------			
0801	220.3	57:	1.18
0831	229.1	986:	1.50
0901	227.5	694:	1.76
0931	226.6	717:	1.82
1001	228.2	733:	1.65
1031	233.3	727:	1.69
1101	231.0	748:	1.78
1131	238.8	777:	1.70
1201	234.7	774:	1.74
1231	238.4	838:	1.69
1301	236.8	818:	1.79
1331	236.8	771:	1.71
1401	241.1	766:	1.74
1431	236.4	719:	1.55
----------DATA MISSING----------			
1531	67.7	76:	1.57
1601	241.2	813:	1.74
1631	240.3	734:	1.57
----------DATA MISSING----------			
1801	244.4	823:	1.55
1831	239.8	809:	1.44
----------DATA MISSING----------			
2001	242.4	723:	1.50
2031	242.0	700:	1.51
----------DATA MISSING----------			
2131	84.9	0:	0.00
2201	235.3	681:	1.43
2231	234.9	635:	1.49
2301	233.3	783:	1.55
2331	236.3	762:	1.41
----------DATA MISSING----------			
0031	229.0	229:	4.77
----------DATA MISSING----------			
0201	227.4	678:	1.38
0231	228.0	699:	1.38
0301	225.4	724:	1.50
0331	226.0	766:	1.55
0401	222.8	754:	1.63
0431	222.0	791:	1.61
0501	222.4	824:	1.57
0531	223.5	801:	1.62
0601	224.9	828:	1.57
0631	227.6	834:	1.60

Table 73. Report for the 24 h ending 0700, 1980 March 20; o.s.h. clock averages.

Time (MST)	Temperature (°C)	SO_2 Concentration (ppm)	SO_2 Rate (LT/h)
0731	232.3	780:	1.60
0801	234.3	847:	1.68
0831	228.8	887:	1.62
0901	233.0	855:	1.66
0931	230.5	1001:	1.96
1001	203.7	438:	0.64
1031	180.2	193:	0.41
1101	175.8	167:	0.41
1131	176.7	157:	0.37
1201	173.4	213:	0.38
1231	165.7	216:	0.41
1301	171.0	241:	0.47
1331	168.9	258:	0.46
1401	170.2	247:	0.40
1431	172.6	240:	0.38
1501	170.0	226:	0.36
1531	163.7	202:	0.33
1601	162.9	212:	0.33
1631	165.0	216:	0.31
1701	166.1	202:	0.31
1731	166.8	176:	0.29
----------	DATA MISSING	----------	----------
2001	162.2	166:	0.30
2031	162.8	161:	0.31
2101	167.1	172:	0.29
2131	166.0	136:	0.27
2201	163.2	118:	0.28
2231	162.0	139:	0.26
2301	162.1	138:	0.27
2331	165.2	151:	0.28
0001	166.5	174:	0.30
0031	159.3	177:	0.32
0101	175.4	554:	1.21
0131	212.8	896:	1.60
0201	217.6	870:	1.60
0231	217.4	674:	1.58
0301	224.3	918:	1.56
0331	229.0	928:	1.60
0401	229.0	842:	1.61
----------	DATA MISSING	----------	----------
0531	225.8	811:	1.49
0601	230.7	806:	1.63
0631	231.2	782:	1.72
0701	229.0	781:	1.72

Table 74. Report for the 24 h ending 0700, 1980 March 21; o.s.h. clock averages.

Time (MST)	Temperature (°C)	SO_2 Concentration (ppm)	SO_2 Rate (LT/h)
0801	84.7	100:	2.07
0831	233.6	875:	1.59
	-DATA MISSING-		
1001	225.2	865:	1.54
1031	226.3	858:	1.50
1101	227.7	842:	1.53
1131	233.3	897:	1.56
1201	231.7	828:	1.48
1231	226.5	906:	1.57
1301	231.6	813:	1.55
1331	231.8	799:	1.36
1401	228.1	749:	1.38
	-DATA MISSING-		
1501	69.8	78:	1.62
1531	226.0	781:	1.46
1601	229.3	799:	1.16
1631	226.9	923:	1.44
1701	225.5	757:	1.34
1731	239.0	828:	1.43
1801	236.4	892:	1.67
1831	244.0	744:	1.38
1901	241.5	848:	1.32
1931	242.2	834:	1.30
2001	240.6	798:	1.33
2031	244.0	781:	1.28
2101	243.9	807:	1.36
2131	242.6	790:	1.51
2201	242.0	848:	1.49
	-DATA MISSING-		
2301	722.6	806:	16.79
2331	247.1	801:	1.39
0001	242.0	808:	1.39
0031	241.8	752:	1.42
0101	243.2	791:	1.49
0131	245.9	805:	1.44
0201	242.5	843:	1.48
0231	240.2	818:	1.57
0301	243.7	855:	1.53
	-DATA MISSING-		
0401	277.2	244:	5.08
0431	239.9	866:	1.66
0501	241.6	739:	1.67

Table 74. Concluded.

----------DATA MISSING----------			
0601	636.5	712:	14.83
0531	238.6	770:	1.56
0701	243.6	682:	1.40

Table 75. Report for the 24 h ending 0700, 1980 March 22; o.s.h. clock averages.

Time (MST)	Temperature (°C)	SO_2 Concentration (ppm)	SO_2 Rate (LT/h)
0731	208.0	274:	0.57
----------	DATA MISSING	----------	----------
0831	168.6	188:	3.92
0901	182.7	285:	0.53
0931	179.3	273:	0.51
1001	181.3	273:	0.53
1031	190.3	318:	0.63
1101	197.0	316:	0.57
1131	196.0	327:	0.57
1201	196.2	311:	0.57
1231	197.3	310:	0.55
1301	199.7	207:	0.53
1331	198.4	302:	0.53
1401	199.8	309:	0.52
1431	197.9	231:	0.54
1501	203.3	275:	0.50
----------	DATA MISSING	----------	----------
1601	178.9	200:	4.17
1631	198.3	311:	0.58
1701	199.9	327:	0.63
1731	203.3	325:	0.66
1801	205.1	669:	1.19
1831	234.5	1436:	2.83
1901	237.3	1456:	3.00
1931	232.7	1428:	3.16
2001	230.0	1358:	2.93
----------	DATA MISSING	----------	----------
2101	150.0	166:	3.45
2131	236.2	1509:	3.51
2201	231.7	1529:	3.50
2231	234.9	1656:	3.81
2301	233.6	1472:	3.48
0001	234.2	1561:	3.54
0031	232.0	1496:	3.52
0101	229.8	1501:	3.52
0131	231.2	1452:	3.40
0201	235.3	1419:	3.26
0231	232.5	1421:	3.14
0301	234.5	1297:	2.74
0331	231.4	1230:	2.76
0401	231.5	1382:	3.32

continued ...

Table 75. Concluded.

0431	234.2	1383:	3.14
0501	236.1	1316:	2.97
0531	241.0	1367:	2.81
0601	240.9	1156:	2.55
0631	238.8	1143:	2.58
0701	240.7	1306:	2.71

Table 76. Report for the 24 h ending 0700, 1980 March 25; o.s.h. clock averages.

Time (MST)	Temperature (°C)	SO_2 Concentration (ppm)	SO_2 Rate (LT/h)
0731	225.0	1168:	2.60
0801	224.9	1280:	2.99
0831	225.3	1601:	3.49
0901	226.3	1543:	3.46
0931	231.0	1495:	3.25
1001	228.1	2196:	0.86
----------DATA MISSING----------			

Table 77. Report for the 24 h ending 0700, 1980 March 26; o.s.h. clock averages.

Time (MST)	Temperature (°C)	SO_2 Concentration (ppm)	SO_2 Rate (LT/h)
0731	225.0	1168:	2.60
----------DATA MISSING----------			

Table 78. Report for the 24 h ending 0700, 1980 June 28; o.s.h. clock averages.

Time (MST)	Temperature (°C)	SO_2 Concentration (ppm)	SO_2 Rate (LT/h)
0731	268.8	1495:	2.92
0801	268.3	1719:	3.84
0831	267.0	2411:	5.14
0901	264.4	1658:	3.33
0931	264.2	1831:	3.77
1001	263.4	1832:	3.62
1031	262.8	1645:	3.10
1101	264.7	1579:	2.93
1131	265.8	1833:	3.43
1201	266.8	1904:	3.71
1231	267.1	1553:	2.82
1301	266.7	1417:	2.71
1331	266.6	1537:	2.77
1401	267.4	1532:	2.75
1431	266.3	1615:	2.85
1501	265.4	1641:	3.08
1531	262.3	1807:	3.50
1601	253.3	2016:	4.19
1631	249.9	1408:	2.72
1701	249.0	1333:	2.56
1731	249.8	1368:	2.58
1801	251.4	1408:	2.79
1831	252.0	1343:	2.64
1901	251.9	1276:	2.59
1931	250.9	1270:	2.55
2001	250.2	1248:	2.61
2031	249.5	1323:	2.76
2101	249.4	1560:	3.59
2131	249.0	1623:	4.22
2201	249.5	1339:	2.93
2231	248.7	1419:	3.24
2301	248.8	1652:	3.80
2331	248.9	1525:	3.46
0001	249.2	1463:	3.36
0031	248.3	1486:	3.53
0101	248.5	1497:	3.44
0131	248.1	1735:	4.02
0201	246.9	1563:	3.69
0231	246.9	1518:	3.68

continued ...

Table 78. Concluded.

0301	248.5	1572:	3.77
0331	248.2	1588:	3.84
0401	247.6	1614:	3.91
0431	248.1	1599:	3.90
0501	246.8	1619:	3.96
0531	246.0	1577:	3.88
0601	246.1	1589:	3.90
0631	246.1	1600:	3.86
0701	246.5	1641:	3.87

Table 79. Report for the 24 h ending 0700, 1980 June 29; o.s.h. clock averages.

Time (MST)	Temperature (°C)	SO_2 Concentration (ppm)	SO_2 Rate (LT/h)
0731	253.8	1688:	3.97
0801	258.9	1702:	3.89
0831	259.6	1741:	3.81
0901	259.1	1718:	3.78
0931	257.8	1711:	3.64
1001	259.5	1788:	3.63
1031	260.3	1749:	3.49
1101	260.7	1742:	3.43
1131	259.9	1698:	3.31
1201	260.0	1698:	3.26
1231	254.6	1607:	3.20
1301	252.2	1689:	3.36
1331	251.9	1561:	3.00
1401	252.4	1439:	2.93
1431	252.5	1532:	2.86
1501	252.8	1432:	2.84
1531	254.0	1478:	2.91
1601	253.7	1639:	3.33
1631	252.8	1803:	3.67
1701	251.0	2132:	4.42
1731	250.2	2266:	4.89
1801	250.3	2797:	6.01
1831	251.5	2723:	5.71
1901	250.3	2167:	4.35
1931	250.7	1929:	3.89
2001	250.6	1822:	3.56
2031	249.6	1912:	3.86
2101	248.3	1686:	3.31
2131	248.5	1451:	2.70
2201	247.1	1437:	2.87
2231	246.5	1377:	2.73
2301	247.4	1389:	2.77
2331	247.6	1437:	2.96
0001	247.1	1415:	2.97
0031	248.0	1412:	2.95
0101	248.1	1419:	3.03
0131	247.8	1433:	3.12
0201	248.3	1487:	3.26
0231	247.8	1489:	3.22
0301	247.9	1527:	3.35

continued ...

Table 79. Concluded.

0331	246.1	1435:	3.40
0401	244.9	1514:	3.52
0431	243.2	1559:	3.57
0501	242.8	1630:	3.72
0531	242.8	1604:	3.67
0601	244.4	1613:	3.71
0631	244.3	1599:	3.76
0701	256.0	1571:	3.67

Table 80. Report for the 24 h ending 0700, 1980 July 05; o.s.h. clock averages.

Time (MST)	Temperature (°C)	SO_2 Concentration (ppm)	SO_2 Rate (LT/h)
0801	246.6	1190:	2.29
0831	248.5	1291:	2.42
0901	248.8	1375:	2.44
0931	250.6	1376:	2.32
1001	251.1	1285:	2.10
1031	252.7	1301:	2.11
1101	252.3	1214:	1.85
1131	251.7	1220:	1.82
1201	250.8	1276:	1.84
1231	250.3	1243:	1.72
1301	250.5	1148:	1.57
1331	252.7	1160:	1.52
1401	252.2	1220:	1.52
1431	255.1	1165:	1.42
1501	257.4	1065:	1.25
1531	259.1	1163:	1.33
1601	260.5	1115:	1.22
1631	257.4	1159:	1.37
1701	254.8	1153:	1.33
1731	254.8	1166:	1.44
1801	252.0	1069:	1.16
1831	248.7	1209:	1.50
1901	246.0	1304:	1.83
1931	246.5	1220:	1.73
2001	245.0	1225:	1.83
2031	246.5	1440:	2.13
2101	247.1	1296:	1.94
2131	247.0	1319:	2.04
2201	246.2	1290:	1.96
2231	245.7	1252:	1:92
2301	245.8	1285:	1.99
2331	244.5	1273:	2.01
0001	243.9	1256:	2.12
0031	245.3	1292:	2.23
0101	244.8	1309:	2.24
0131	246.0	1246:	2.34
0201	246.1	1399:	2.57
0231	243.4	1719:	3.40
0301	241.1	2127:	4.37

continued ...

Table 80. Concluded.

0331	240.3	2238:	4.74
0401	241.3	2349:	5.32
0431	243.3	1687:	3.37
0501	243.5	1413:	2.79
0531	244.4	1369:	2.74
0601	244.5	1393:	2.82
0631	245.4	1347:	2.74
0701	246.8	1389:	2.87

Table 81. Report for the 24 h ending 0700, 1980 July 06; o.s.h. clock averages.

Time (MST)	Temperature (°C)	SO_2 Concentration (ppm)	SO_2 Rate (LT/h)
0731	247.3	1386:	2.94
0801	249.0	1370:	2.86
0831	247.0	1387:	2.87
0901	245.6	1402:	2.79
0931	245.3	1400:	2.87
1001	246.4	1426:	2.80
1031	247.4	1431:	2.69
1101	248.7	1510:	2.76
1131	249.7	1844:	3.33
1201	249.6	3162:	6.85
1231	249.9	1900:	3.38
1301	249.1	1657:	3.03
1331	250.2	1597:	2.71
1401	250.7	1515:	2.58
1431	251.2	1516:	2.56
1501	250.5	1557:	2.64
1531	250.9	1566:	2.72
1601	250.5	1528:	2.63
1631	259.1	1460:	2.56
1701	246.0	1471:	2.61
1731	245.2	1517:	2.73
1801	245.2	1548:	2.84
1831	245.5	1554:	2.91
1901	245.6	1562:	2.91
1931	245.2	1565:	3.02
2001	246.2	1756:	3.54
2031	243.9	1835:	3.55
2101	243.5	1595:	3.19
2131	242.4	1636:	3.21
2201	242.0	1667:	3.19
2231	241.7	1704:	3.47
2301	243.6	1675:	3.49
2331	243.9	1688:	3.50
0001	244.4	1686:	3.96
0031	244.7	2006:	4.39
0101	244.1	1684:	3.67
0131	244.8	1981:	4.75
0201	245.8	3191:	8.32
0231	246.3	1831:	4.02

continued ...

Table 81. Concluded.

0301	246.2	2049:	4.56
0331	244.4	1330:	4.10
0401	242.4	1779:	4.07
0431	243.8	1767:	4.04
0501	241.8	1785:	4.10
0531	241.8	1766:	4.12
0601	241.7	1773:	4.16
0631	244.0	1706:	3.99
0701	244.1	1670:	3.91

Table 82. Report for the 24 h ending 0700, 1980 July 08; o.s.h. clock averages.

Time (MST)	Temperature (°C)	SO_2 Concentration (ppm)	SO_2 Rate (LT/h)
0731	238.2	1278:	3.02
0801	238.4	1189:	2.63
0831	235.4	1269:	2.73
0901	234.3	1010:	2.19
0931	234.4	1015:	2.08
1001	236.0	998:	2.03
1031	237.7	1007:	1.94
1101	242.6	923:	1.62
1131	243.8	975:	1.67
1201	243.9	952:	1.57
1231	245.8	1007:	1.60
1301	246.9	1165:	1.90
1331	248.8	1270:	2.11
1401	250.4	1193:	1.98
1431	252.3	1287:	2.10
1501	253.3	1363:	2.12
1531	251.6	1410:	2.11
1601	250.9	1385:	2.07
1631	252.5	1398:	2.04
1701	252.0	1436:	2.13
1731	248.6	1427:	2.06
1801	248.6	1586:	2.33
1831	248.4	1719:	2.62
1901	248.1	1643:	2.43
1931	248.3	1683:	2.56
2001	246.5	1618:	2.41
2031	245.6	1653:	2.58
2101	243.8	1692:	2.67
2131	243.4	1559:	2.52
2201	244.3	1567:	2.63
2231	243.9	1569:	2.72
2301	243.7	1527:	2.76
2331	245.4	1591:	2.89
0001	245.5	1636:	2.94
0031	243.1	1673:	3.22
0101	243.0	1588:	2.89
0131	243.0	1647:	3.11
0201	243.6	1642:	3.15

continued ...

Table 82. Concluded.

0231	245.4	1677:	3.21
0301	248.4	1727:	3.45
0331	251.8	1933:	3.88
0401	253.2	1777:	3.50
0431	253.4	1726:	3.45
0501	253.6	1693:	3.44
0531	253.0	1714:	3.50
0601	251.7	1741:	3.58
0631	250.8	1763:	3.64
0701	252.2	1799:	3.77

Table 83. Report for the 24 h ending 0700, 1980 July 09; o.s.h. clock averages.

Time (MST)	Temperature (°C)	SO_2 Concentration (ppm)	SO_2 Rate (LT/h)
0731	252.3	2035:	4.39
0801	252.8	1950:	4.06
0831	253.4	2044:	4.47
0901	252.5	2028:	4.20
0931	254.5	2022:	4.12
1001	256.5	2013:	4.04
1031	255.2	1866:	3.69
1101	255.7	1951:	3.70
1131	256.9	1056:	3.72
1201	253.4	2108:	4.13
1231	259.9	2063:	3.79
1301	260.9	2298:	4.38
1331	261.1	2139:	3.98
1401	261.6	2030:	3.86
1431	260.9	1898:	3.52
1501	260.7	2130:	3.82
1531	256.7	1677:	2.80
1601	258.2	1829:	3.16
1631	258.5	2013:	3.57
1701	260.8	1995:	3.56
1731	262.4	1920:	3.46
1801	262.6	2030:	3.71
1831	261.4	1758:	3.00
1901	262.6	1314:	3.22
1931	260.9	1674:	2.98
2001	257.3	1791:	3.24
2031	255.5	1749:	3.29
2101	254.6	1883:	3.62
2131	254.5	1897:	3.79
2201	255.6	1853:	3.79
2231	256.9	1874:	3.75
2301	256.8	1929:	3.87
2331	257.9	1913:	3.81
0001	255.6	1965:	3.91
0031	256.4	1925:	3.81
0101	257.0	1926:	3.82
0131	256.5	1914:	3.89
0201	257.5	1913:	3.92

continued ...

Table 83. Concluded.

0231	254.7	1836:	3.86
0301	254.8	2132:	4.61
0331	258.8	2146:	4.43
0401	260.0	2265:	4.62
0431	260.6	1937:	4.15
0501	258.3	2207:	5.09
0531	256.1	2076:	4.44
0601	256.0	2073:	4.53
0631	255.4	2212:	4.87
0701	256.3	2230:	4.78

6.6.2 Emission Data from Power House Stack of Suncor Ltd.

During the periods that field measurements were made, Suncor did not have continuous emission monitors in operation. Daily emissions reported by Suncor are therefore based on coke consumption in the power house. Experience by Suncor has shown that these estimates are 10 to 20% higher than the surveyed values. These data are presented in Table 84.

Typical concentrations from stack surveys of the power house have been as follows: SO_2: 3700 ppm (V/V); NO_x: 500 ppm (V/V); SO_3: 3 kg/h as H_2SO_4 while typical numbers for emission rate and temperature are 400 $m^3 \cdot S^{-1}$ and 270°C, respectively. Using these data, it would appear that less than 0.05% of the total emitted sulphur is in the form of SO_3. Such a low value is highly unlikely and certainly at odds with airborne observations close to the stack (the latter observations would indicate particulate sulphur in the order of more than 1% of total emitted sulphur). Hence, the typical number for SO_3 is discarded as incorrect. The present author is no expert on stack gas sampling but would recommend review of the method presently employed by Alberta Environment.

Table 84. Estimated daily emission (tonnes) of SO_2 from the powerhouse stack of Suncor Ltd.

January	9	270
	10	260
	11	262
	13	292
March	18	316
	19	192
	20	206
	21	228
	24	198
	25	164
June	25	206
	27	218
	28	230
July	4	234
	5	334
	7	224
	8	232

6.6.3 Radiation Data

AOSERP is operating an Eppley 180° pyrheliometer at the Mildred Lake camp to document the total irradiation in the study area. The data are documented in the form of 1 h integrated values, and the observations made during the times of the present field study are reproduced here in graphical form (Figures 69 to 86).

During the June/July period of this study, the total UV radiation was also recorded. For this purpose, an Eppley Solar and Sky U-V radiometer was installed at the Mildred Lake camp. This instrument had a wavelength response between 295 to 385 mμ, and the observations are included for the appropriate dates. In the following graphs drawn lines represent total radiation data, while dashed lines show data from the UV radiometer.

Figure 69. Radiation data for 80-01-09.

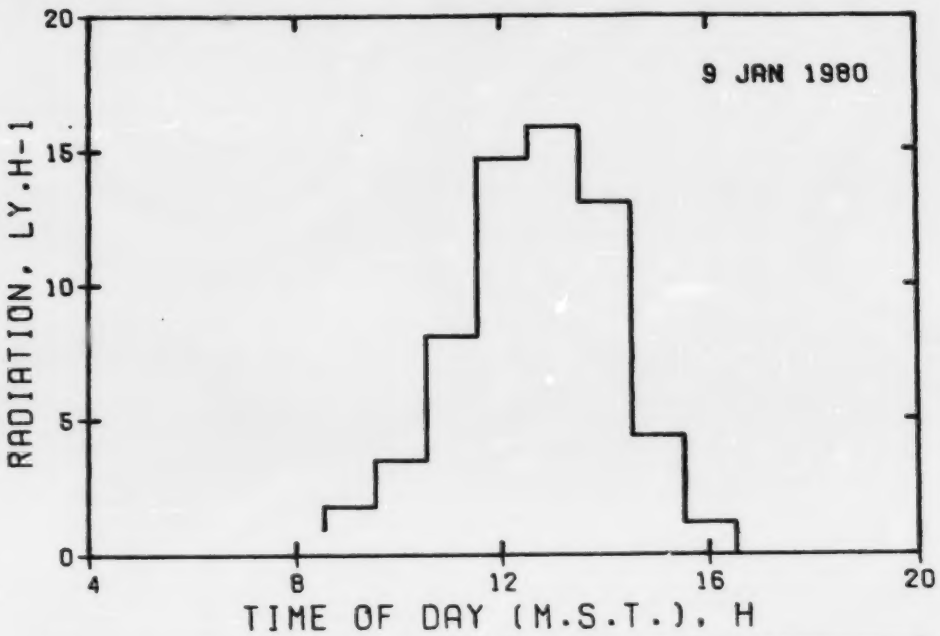


Figure 70. Radiation data for 80-01-10.

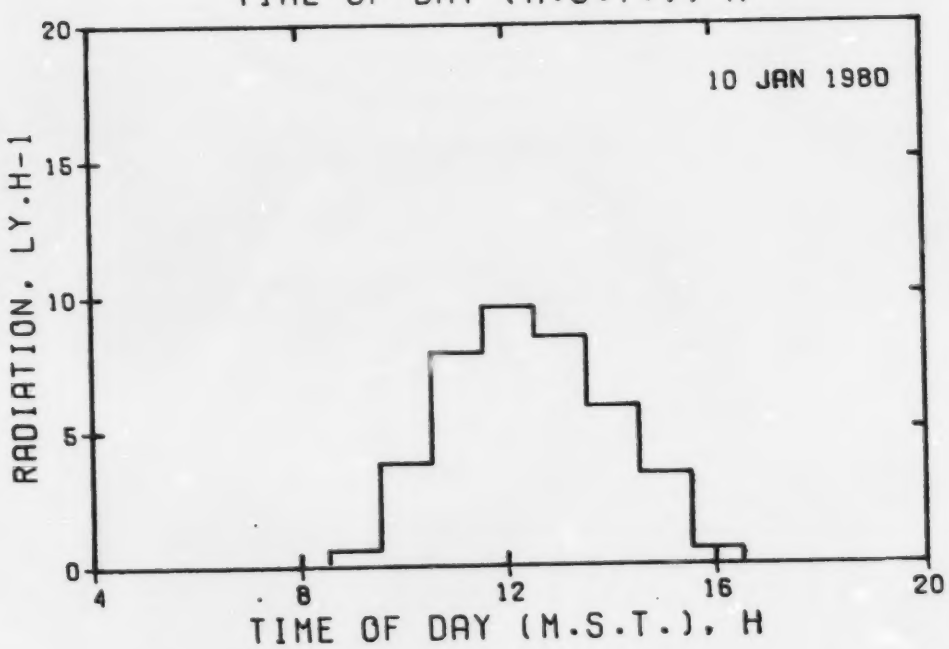


Figure 71. Radiation data for 80-01-11.

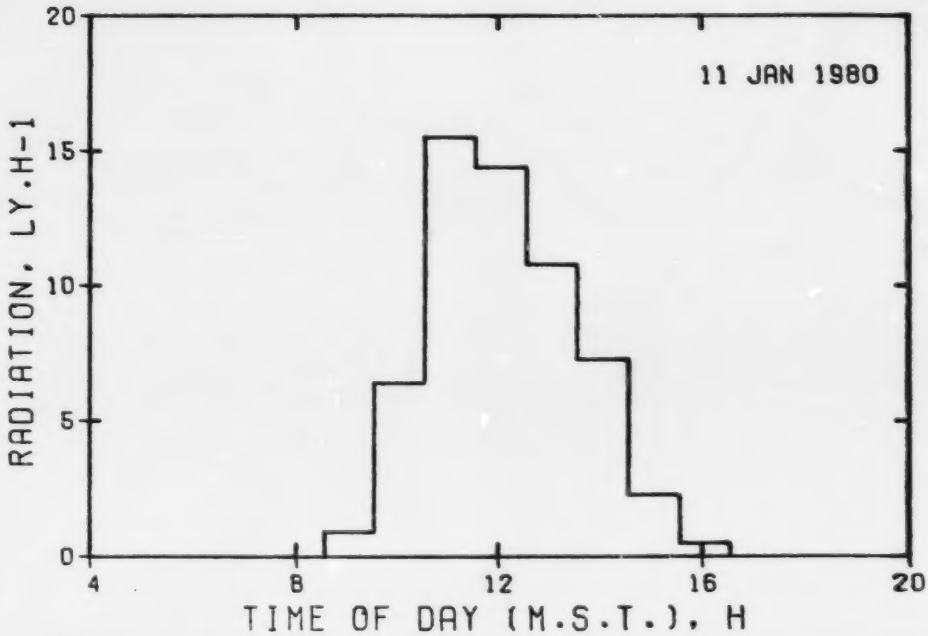


Figure 72. Radiation data for 80-01-12.

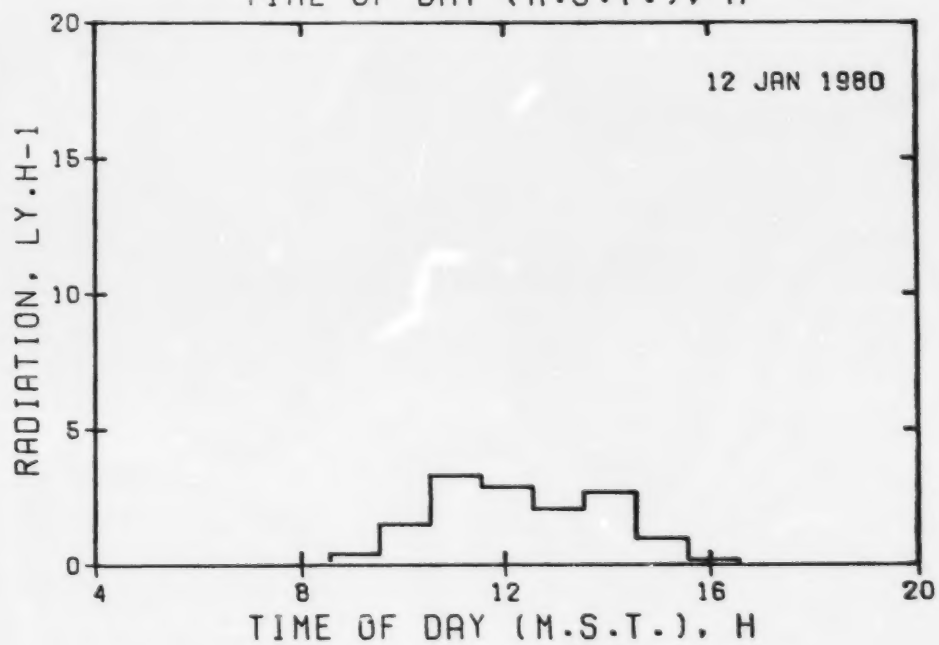
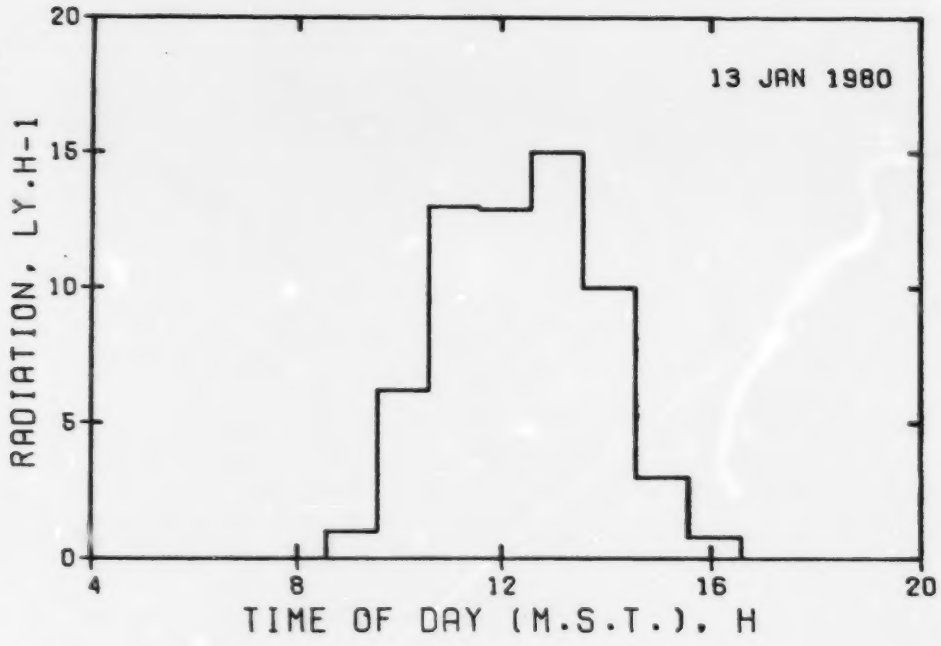


Figure 73. Radiation data for 80-01-13.



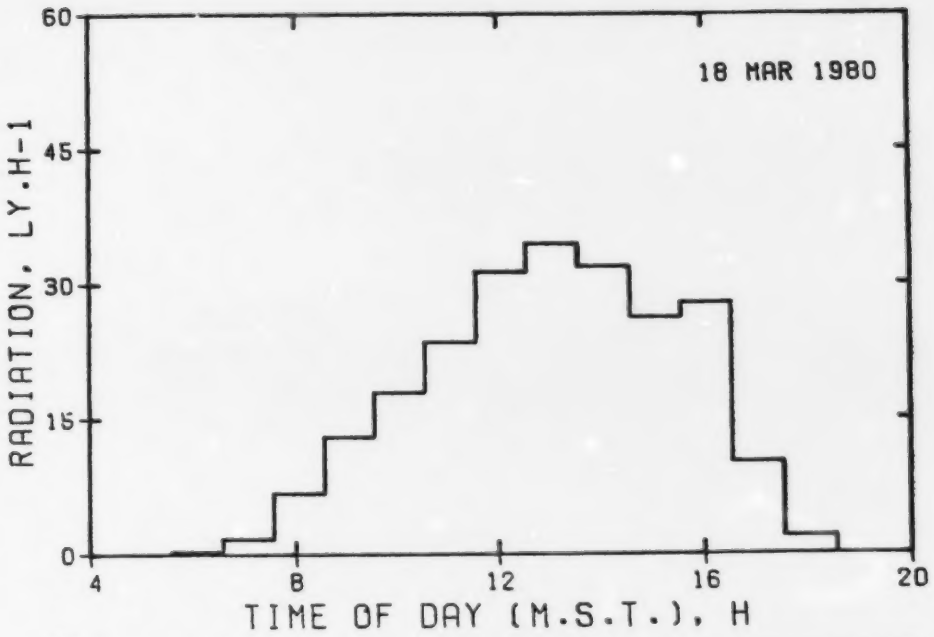


Figure 74. Radiation data for 80-03-18.

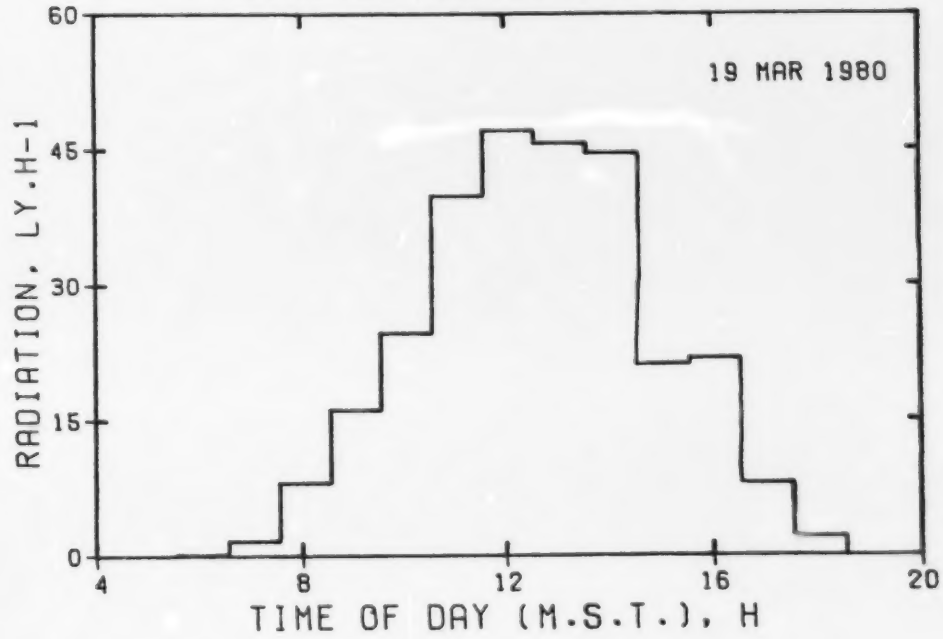


Figure 75. Radiation data for 80-03-19.

Figure 76. Radiation data for 80-03-20.

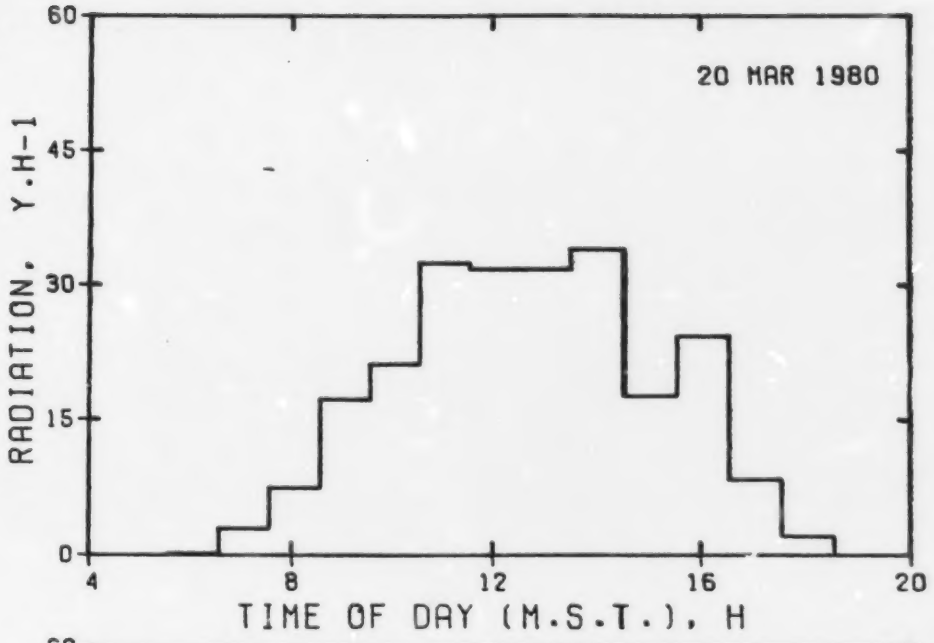


Figure 77. Radiation data for 80-03-21.

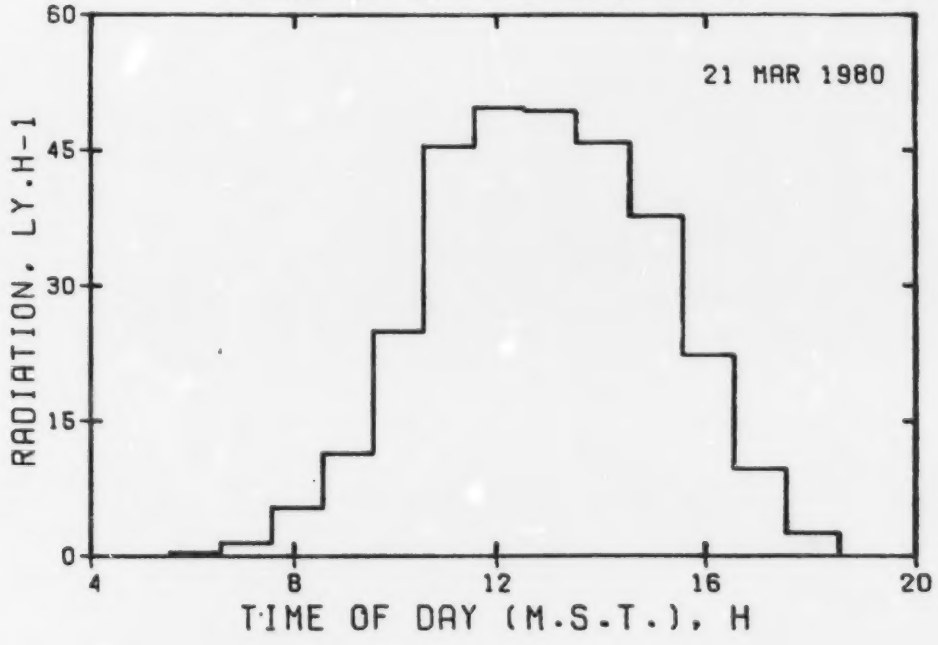


Figure 78. Radiation data for 80-03-24.

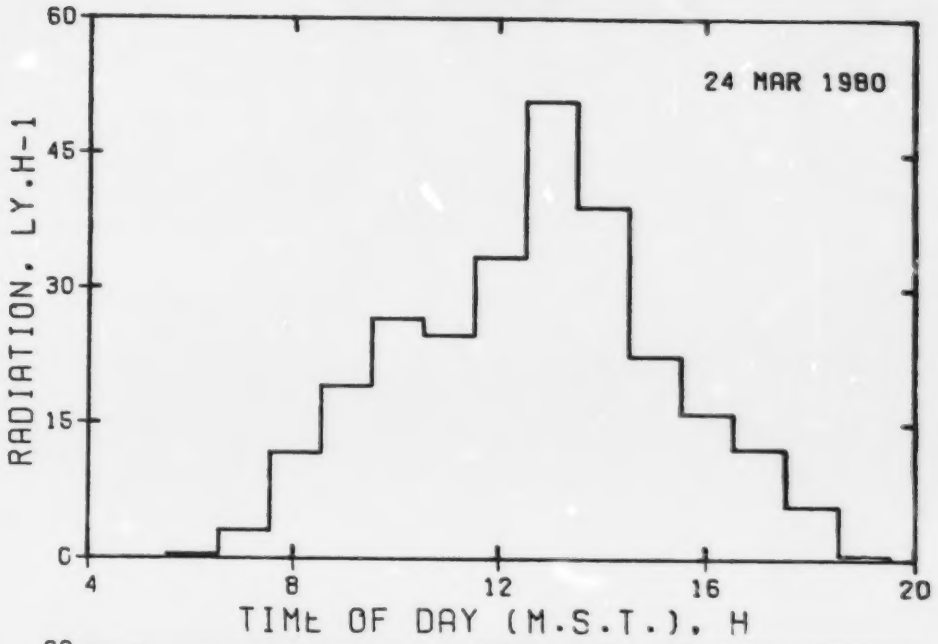


Figure 79. Radiation data for 80-03-25.

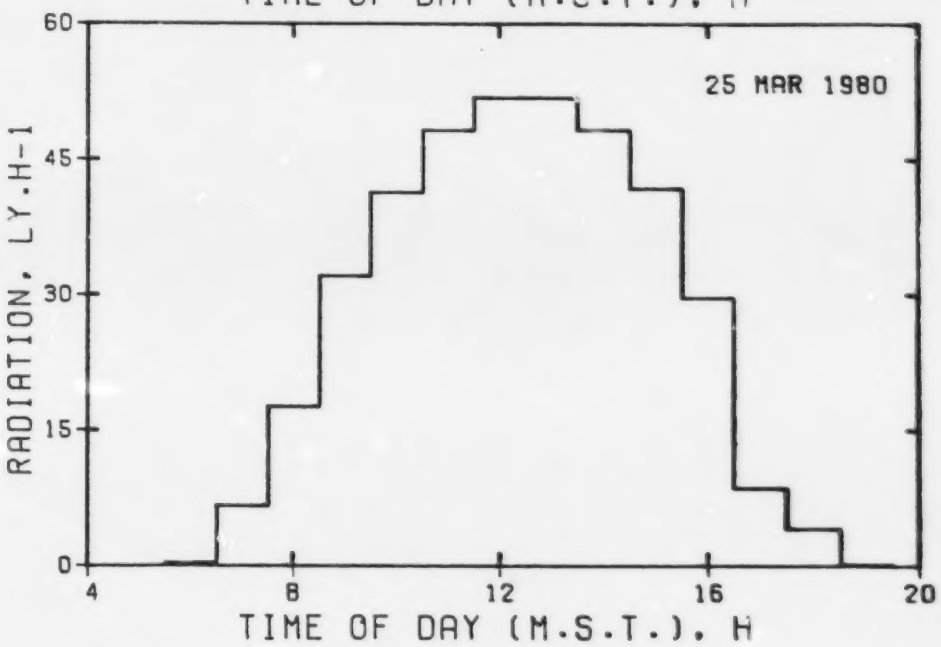


Figure 80. Radiation data for 80-06-25.

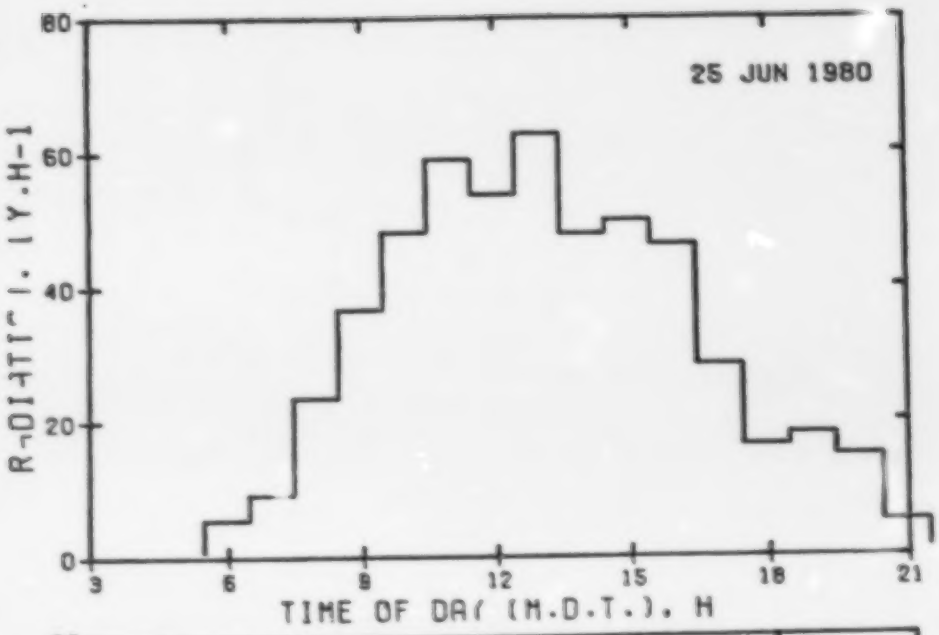


Figure 81. Radiation data for 80-06-27.

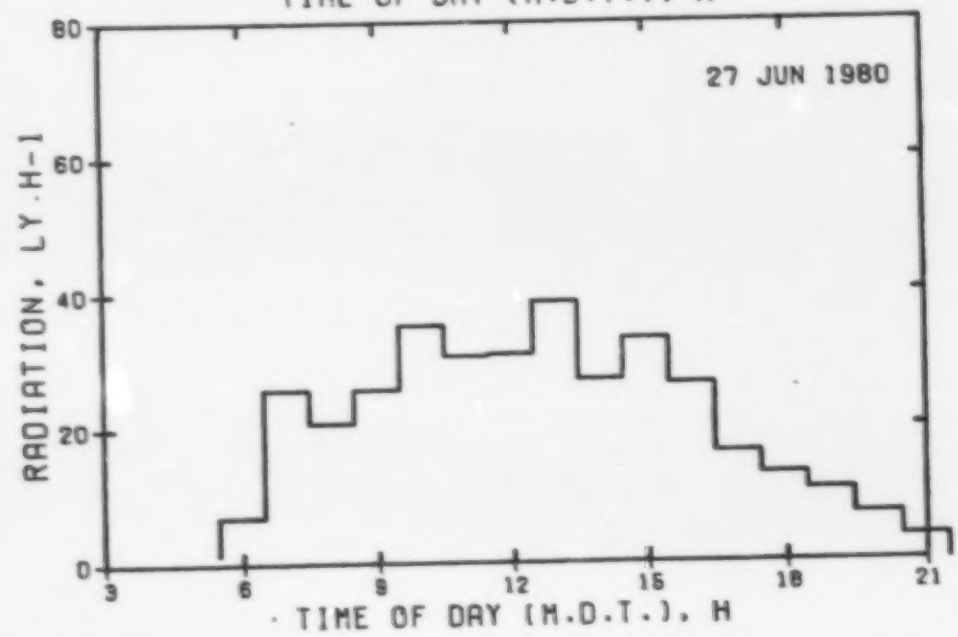


Figure 82. Radiation data for 80-06-28.

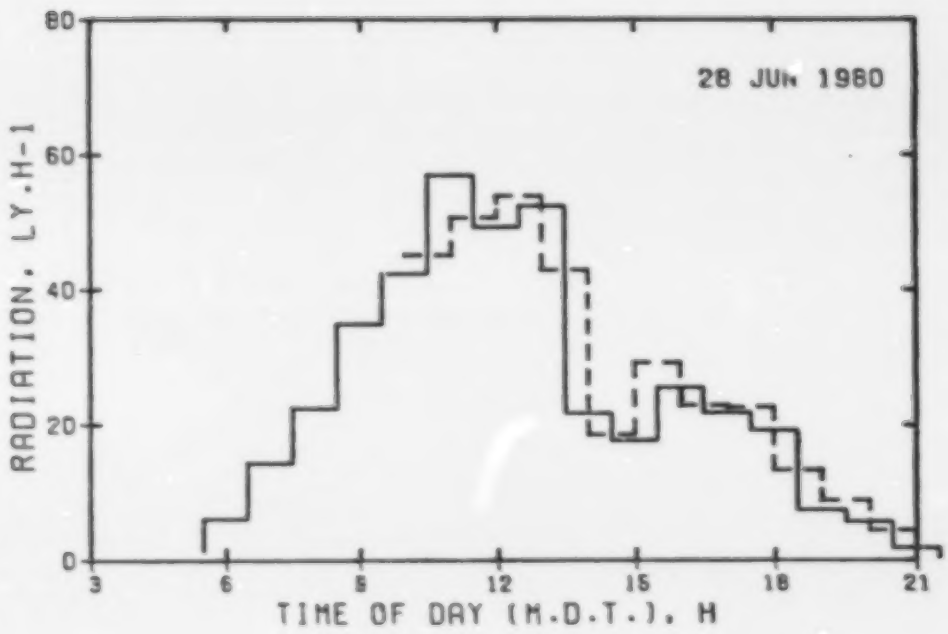


Figure 83. Radiation data for 80-07-04.

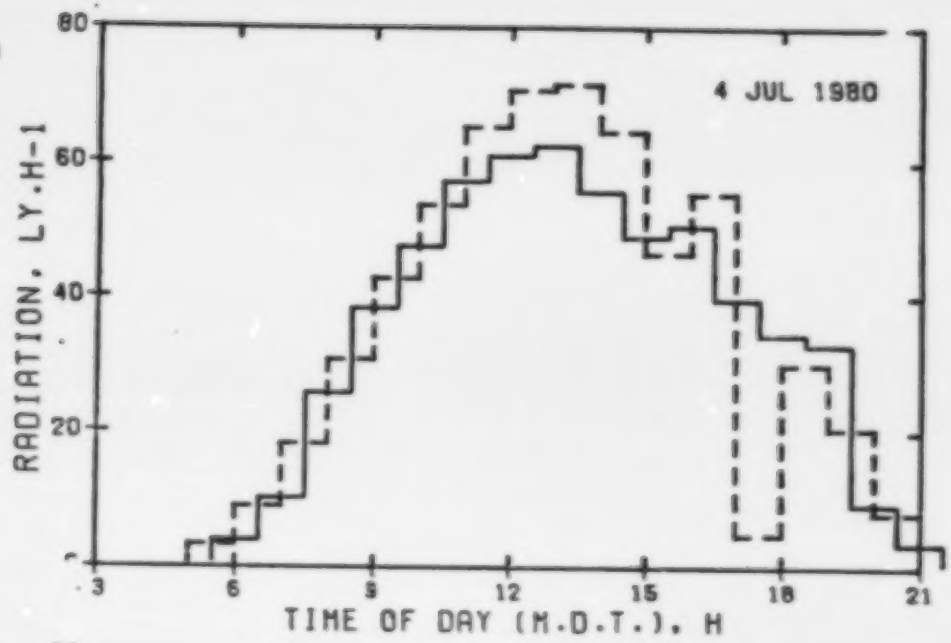


Figure 84. Radiation data for 80-07-05.

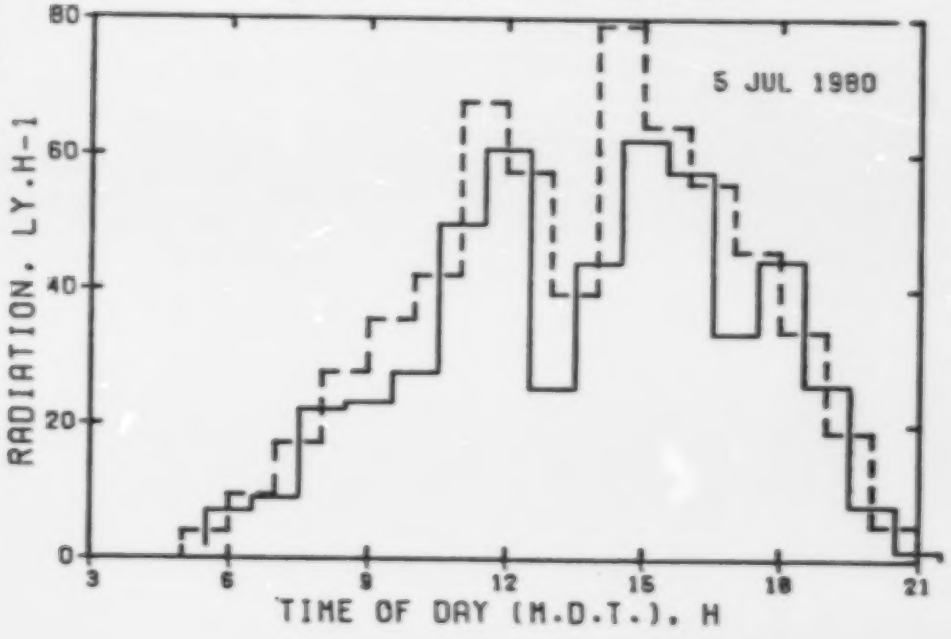


Figure 85. Radiation data for 80-07-07.

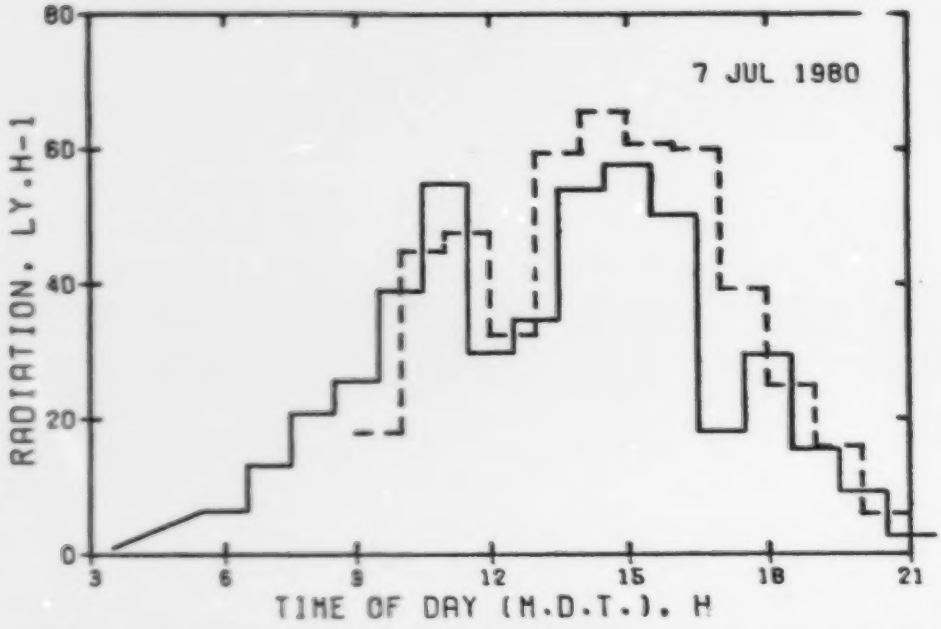
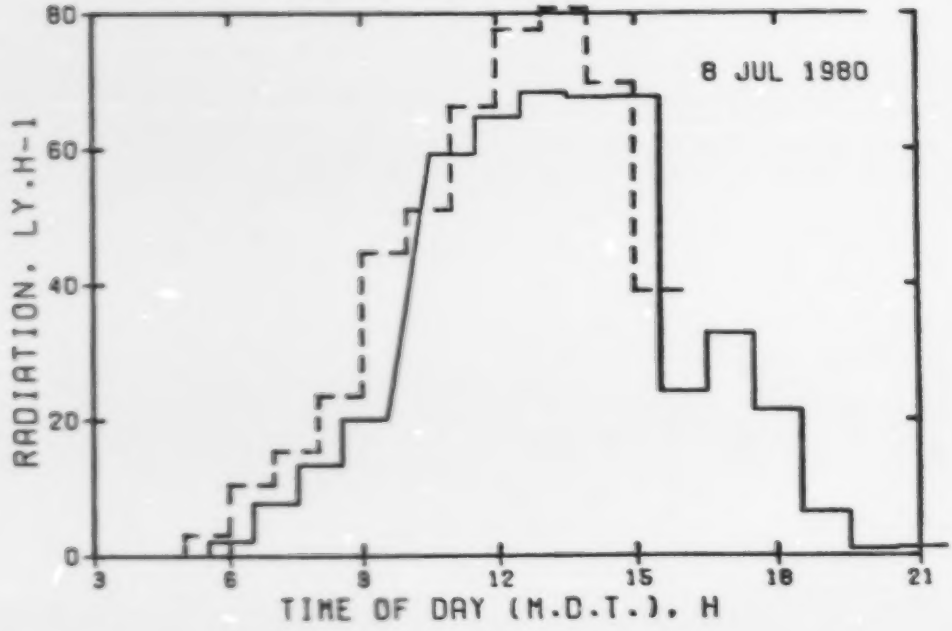


Figure 86. Radiation data for 80-07-08.



6.6.4 Observations at Lower Syncrude Camp Meteorological Tower

A 500 ft meteorological tower is operated by AOSERP at the lower Syncrude camp as part of the automated MAP-network in the study area. The exact position of the tower is at 57° o2" N, 111° 31" W, and its elevation is 790 ft MSL (ca 241 m). The tower reports hourly data for temperature (at 15, 10, 30, 90, and 152 m), windspeed (10, 90, and 152 m), and wind direction. Unfortunately, its position in the Athabasca River valley renders its data of limited value when estimating conditions at the elevation where most observations during this study were made (D. Leahey, Western Research and Developoment, Calgary, Alberta, private communication, 1980). For completeness, the data recorded during the period that this study was under way will be presented in Tables 85-87. A problem developed with the temperature readings during 1980. The data set for temperatures is only reported here, when it can be considered reasonably reliable.

Table 85. Lower Syncrude tower data, January 1980.

Date	Time (MST)	T_{10}	$T_{1.5}-T_{10}$	$T_{30}-T_{10}$	$T_{90}-T_{10}$	$T_{152}-T_{10}$	W_{30}	W_{90}	W_{152}
09 Jan.	1000	-31.4	-1.0	+0.8	ND	+0.4	15-10	17-11	19-12
	1100	-29.3	-0.5	+0.3	ND	-0.6	15-10	16-10	16-12
	1200	-27.3	-0.7	0.0	ND	-1.0	15-10	16-12	17-14
	1700	-26.8	-1.7	+0.4	ND	+1.4	16-06	17-11	19-09
	1800	-27.9	-1.4	+0.9	ND	+1.7	16-06	17-06	22-09
	1900	-28.3	-1.8	+0.6	ND	+1.8	17-05	18-06	22-08
10 Jan.	1100	-29.6	-0.1	-0.3	ND	-0.2	32-04	35-09	01-14
	1200	-27.1	0.0	-0.3	ND	-1.6	00-05	00-10	00-11
	1300	-27.0	+0.1	-0.3	ND	-1.8	00-06	00-13	01-14
	1400	-27.2	0.0	-0.2	ND	-1.7	00-05	00-12	00-12
11 Jan.	1300	-33.6	-0.2	+0.2	ND	+1.7	16-06	15-06	13-09
	1400	-32.4	+0.2	+0.3	+1.4	+1.4	16-06	15-03	16-06
	1500	-32.8	-0.1	+0.3	ND	+2.1	00-00	13-04	15-06
	1600	-33.3	-0.4	+0.2	ND	+2.9	00-00	00-00	12-06
	1700	-33.8	-1.1	+0.1	ND	+3.2	00-00	17-02	16-05
13 Jan.	1000	-18.8	-0.4	+0.3	+0.6	+0.8	18-03	18-10	17-15
	1100	-18.7	-0.4	+0.6	+0.5	+0.7	15-06	16-07	16.13

Table 85. Continued.

Date	Time (MST)	T_{10}	$T_{1.5}-T_{10}$	$T_{30}-T_{10}$	$T_{90}-T_{10}$	$T_{152}-T_{10}$	W_{30}	W_{90}	W_{152}
	1200	-18.6	0.0	+0.3	+0.6	+0.7	14-06	15-09	13-13
	1300	-18.4	0.0	0	+0.4	+0.6	00-00	17-09	15-12
	1400	-18.2	-0.6	+0.1	+0.6	+0.6	18-02	15-08	14-12
	1500	-18.1	+0.1	+0.5	+0.1	0	18-02	16-10	15-14
	1600	-18.0	-0.9	+0.2	+0.5	+0.4	30-03	17-04	16-10
	1700	-18.2	-1.3	+0.7	+2.2	+1.9	34-02	29-01	16-05

Table 86. Lower Syncrude tower data, March 1980.

Date	Time (MST)	W_{30}	W_{90}	W_{152}
18 March	1500	01-04	01-05	34-03
	1600	04-03	04-04	03-04
	1700	05-04	05-05	04-03
	1800	00-00	04-04	05-05
19 March	1700	00-00	00-00	24-03
	1800	00-00	26-03	26-04
	1900	00-00	28-03	28-04
	2000	30-02	34-10	34-12
20 March	1000	36-04	36-05	01-05
	1100	02-03	35-04	34-03
	1200	01-03	36-03	36-02
	1300	36-04	33-05	33-05
	1400	35-05	34-07	34-06
	1500	35-06	36-10	36-09
21 March	1200	35-04	35-09	36-09
	1300	36-05	34-08	35-08
	1400	32-07	33-08	33-09
	1500	33-05	33-06	33-06
	1600	30-04	32-05	32-05
	1700	29-05	29-07	30-06
	1800	00-00	33-06	34-06
	1900	00-00	00-00	01-03
24 March	0800	35-02	36-07	01-09
	0900	34-05	34-10	35-11
	1000	35-04	35-10	35-10
	1100	35-04	35-10	35-10
	1200	36-05	35-12	36-14
	1300	01-06	36-15	02-14
	1400	01-06	01-11	02-11
25 March	0900	ND	00-00	25-01
	1000	13-01	24-02	27-02
	1100	14-02	00-00	00-00
	1200	19-04	23-04	24-03
	1300	05-02	03-02	00-00
	1400	00-00	00-00	00-00
	1500	17-03	00-00	00-00
	1600	00-00	00-00	00-00

Table 87. Lower Syncrude tower data, June/July 1980.

Date	Time (MST)	T_{10}	$T_{152}-T_{10}$	W_{30}	W_{90}	W_{152}
25 June	2000	19.7	+0.8	15-09	16-12	16-15
	2100	18.3	+0.8	13-08	15-14	16-12
	2200	16.4	+0.4	14-07	14-14	15-15
	2300	15.3	+0.8	15-09	15-16	15-18
28 June	1100	17.2	+1.9	15-10	ND	18-10
	1200	19.4	+2.2	27-05	ND	24-05
	1300	18.9	+2.1	22.08	ND	23-09
	1400	19.4	+1.6	22.08	ND	21-08
	1500	19.7	+1.8	23.09	ND	22-08
	1600	20.0	+1.7	21-09	ND	22-08
04 July	0800	18.3	+1.2	14-07	15-09	16-08
	0900	21.1	+1.4	16-09	17-11	17-10
	1000	21.4	+1.8	15-09	17-10	17-10
	1100	23.9	+2.2	21-07	16-10	20-09
	1200	25.6	+2.3	24-09	19-09	21-08
	1300	25.6	+2.3	22-06	23-08	23-06
05 July	0300	16.9	-3.7	22-02	09-04	13-09
	0400	15.8	-2.8	32-01	09-02	13-08
	0500	16.1	2.3	33-02	04-02	11-06
	0600	15.8	-0.4	36-03	33-04	32-02
	0700	18.1	+0.8	36-03	33-04	32-03
	0800	19.4	+1.1	36-02	32-03	34-01
07 July	0300	10.8	-3.3	22-04	18-04	14-04
	0400	10.8	-3.7	16-05	16-05	14-05
	0500	10.0	-2.2	17-09	17-06	14-06
	0600	9.4	-0.5	18-09	16-08	13-07
	0700	10.3	0.0	17-07	15-08	14-07
	0800	12.2	+0.6	17-09	16-09	13-07
	0900	14.2	+0.8	16-09	15-09	14-08
	1000	ND	+0.9	18-11	15-10	14-08
	1100	ND	+1.2	21-12	21-11	22-10
	1200	ND	+1.9	21-10	21-10	21-10
	1300	ND	+1.7	23-13	22-12	23-10
	1400	ND	+1.7	23-18	22-15	23-10
	1500	ND	+2.1	24-16	23-15	23-12
	1600	ND	+1.9	26-18	26-16	26-10
	1700	ND	+2.0	26-17	26-18	27-08

continued ...

Table 87. Concluded.

Date	Time (MST)	T_{10}	$T_{152}-T_{10}$	W_{30}	W_{90}	W_{152}
	1800	ND	+1.9	35-12	35-11	35-05
	1900	ND	+0.4	31-08	35-06	30-01
08 July	0900	17.2	+1.7	05-02	09-01	18-02
	1000	20.0	+2.5	36-01	30-01	18-02
	1100	22.2	+2.3	34-02	36-02	03-03
	1200	21.1	+0.6	03-01	02-01	06-02
	1300	25.0	+1.1	02-01	02-01	06-03
	1400	25.6	+2.2	36-04	35-03	35-03
	1500	19.4	+1.1	36-10	36-10	33-04
	1600	18.3	+0.8	27-03	31-04	31-04

6.6.5 Syncrude Acoustic Sounder Data

During this study, the environment division of Syncrude Canada Ltd. was in the process of installing a doppler acoustic sounder at the Mildred Lake camp. It is anticipated that, when fully operational, this instrument will be able to routinely record windspeed and wind direction at altitudes up to 500 m AGL over the Syncrude plant site.

During the June/July period of this study, the acoustic sounder could be operated on an experimental ad hoc basis, and data were collected during some of the flights for this study. The data thus collected, are presented in Table 88. A detailed discussion of the instrument and its potential will be given elsewhere (Netterville, Syncrude Canada, Edmonton, Alberta, personal communication, 1980). As in Section 6.6.4, the data are presented for wind direction (in degrees) and windspeed (in m S^{-1}).

Table 88. Syncrude doppler acoustic sounder data during June/July 1980.

Date	Time (MST)	Direction - Speed				
		100 m	200 m	300 m	400 m	500 m
28 June	1100-1130	208-1.4	196-2.0	210-2.4	207-2.2	215-2.8
	1130-1200	217-2.1	191-1.8	197-2.6	203-2.6	187-2.3
	1200-1230	220-2.4	201-2.8	185-2.2	187-2.8	198-3.5
	1230-1300	188-1.5	189-3.1	196-3.4	194-2.8	210-4.2
	1300-1330	203-0.8	184-3.6	194-4.5	187-4.6	190-5.0
	1330-1400	183-1.3	181-2.7	191-3.2	186-4.2	185-4.9
07 July	0500-1530	225-0.2	243-2.6	246-2.6	241.3-5	235-4.4
	0530-0600	45-0.6	246-4.6	237-4.3	241-5.0	238-5.8
	0600-0630	ND	236-5.0	239-6.7	246-6.4	243-5.6
	0930-1000	280-0.9	278-3.2	253-5.5	239-7.5	230-9.0
	1000-1030	281-1.1	274-3.6	258-5.4	245-7.4	236-9.6
	1030-1100	247-1.7	270-4.2	258-5.6	248-7.0	241-8.8
	1300-1330	262-4.4	235-5.8	237-6.2	232-7.5	236-7.9

6.6.6 Minisonde Data

It was intended, during the June/July field trip, to launch minisondes at the time the aircraft was sampling the plumes to obtain, independently, temperature profiles (no personnel would be available to track the minisondes and obtain information on prevailing wind). Unfortunately, due to several circumstances and eventually total equipment failure, only two releases could be called successful. These data are presented in Table 89. Both minisondes were released at the Mildred Lake airstrip.

Table 89. Minisonde data, July 1980.

Time (m)	Temperature (°C) 04 July	05 July
0.5	19.5	19.5
1.0	18.0	19.0
1.5	17.5	18.5
2.0	16.5	18.0
2.5	16.0	18.5
3.0	16.5	18.0
3.5	16.5	17.5
4.0	16.5	17.0
4.5	16.0	17.0
5.0	15.5	17.0
5.5	15.0	17.0
6.0	15.0	16.5
6.5	14.0	15.5
7.0	13.0	15.0
7.5	12.5	14.5
8.0	11.5	13.5
8.5	11.0	13.0
9.0	10.0	12.5
9.5	10.0	12.0
10.0	9.0	11.5
Time of release (MST):	1018	1008
Sky conditions:	slight overcast	overcast
Surface temperature (°C):	23	20.5
Rate of rise (m/sec):	3	3

POOR

QUALITY

ORIGINAL